RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE (*GOPHERUS AGASSIZII*):

2008 AND 2009 REPORTING

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The original design for this project and considerations for optimizing it based on new information and experience were first set out in Anderson and Burnham (1996) and Anderson et al. (2001). Estimation methods were further refined during a 2008 workshop for distance sampling held by S. Buckland, L. Thomas, T. Marques, E. Rexstad, and D. Harris in Marshall, California.

Personnel from Joshua Tree National Park, from Kiva Biological Consulting (California) led by L. Pavlischak (2008) and K. Herbinson (2009) and from the Great Basin Institute (Nevada, Arizona, and the Beaver Dam Slope of Utah) led by T. Christopher conducted the field surveys:

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electronic data-collection forms and procedures each year. R. Learmont (Mojave Desert Ecosystem Program) provided independent review for data submitted by both field groups. M. Brenneman generated the final spatial and non-spatial databases. In 2009, she also developed databases for preseason planning on thousands of potential transects, and for rapid data assessments during the training phase. These have added enormous value to the project in time savings as well as quality assurance.

EXECUTIVE SUMMARY

The recovery program for desert tortoises in the Mojave and Colorado deserts (USFWS, 2011) requires range-wide, long-term monitoring to determine whether recovery goals are met. Specifically, will population numbers within recovery units remain stable or increase over a period of 25 years? In 1999, the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) as the method for estimating range-wide desert tortoise density. From 2001 to 2005, and again from 2007 through 2009, desert tortoise populations in 5 of the 6 recovery units have been part of a coordinated, range-wide monitoring program using line distance sampling. (The Upper Virgin River Recovery Unit is monitored by Utah Division of Wildlife Resources (McLuckie et al., 2012).) The first 5 years of monitoring culminated in a summary report (USFWS, 2006) that included eleven recommendations, seven of which were tied to functioning of the monitoring program and are paraphrased here:

1. The range-wide monitoring program should continue under a formal study plan subject to scientific review.
2. Refine [line distance sampling] techniques to improve sampling efficiency and estimates of trends.
3. Evaluate the spatial scale of the monitoring program.
4. Improve training lines.
5. Evaluate the use of independent field teams in order to improve data consistency and quality.
6. Refine and formalize/document the QA/QC process.
7. Identify and assess options for securing continued funding for range-wide population monitoring.

This report describes the full set of quality assurance steps and final results for the 2008 and 2009 monitoring efforts. Since monitoring started again in 2007, the above recommendations guided improvements to the program (USFWS, 2009a). In 2008, the focus continued, with particular emphasis on a more comprehensive training program, on the premise that training is the opportunity to develop and evaluate quality data collection and to build consistency between separate field teams. An expanded monitoring handbook was written as a reference for objective-driven training. The period of specialized distance sampling training was extended, following general desert and field skills training in each of the cooperating field groups. Inexperienced crews as well as those with prior experience participated in preseason training and testing provided by the University of Nevada, Reno, and by the U.S. Geological Survey in 2008. In 2009, this training was provided directly by the USFWS. In-depth examination of training results after the 2008 field season made it clear that better real-time evaluation was needed; before the 2009 training session, Topoworks and the USFWS developed a system and database tools for this rapid assessment. In 2009, before leaving training for field data collection, all crews were evaluated quantitatively on their ability to produce appropriate detection curves, detection proportion on the transect line, and measurement accuracy from tortoise models to the transect line.

In addition to the 15 strata established for long-term monitoring, 2 short-term strata were funded for monitoring only in 2008 and 2009, and two more short-term strata were funded by the USFWS on BLM lands north or south of Pahrump, in Nye County, Nevada. Data were collected on transects by 52 (2008) or 53 (2009) field personnel working with two different groups, Kiva Biological and Great Basin Institute. After an intensive, 12-day specialized training session, first-year crews were ready to work with returnees who had only a refresher course; they completed 680 transects (6941km) between 31 March and 30 May in 2008, and 765 transect surveys (7740km) between 1 April and 6 June in 2009. In the course of these surveys, they reported 196 live tortoises in 2008 and 273 in 2009.

Four parameter estimates contribute to final reported tortoise densities in each monitoring stratum. The basis for distance sampling is the estimation of the number of tortoises detected at increasing distances from the walked transect. As surveyors look farther from the transect centerline, they will detect fewer and fewer of the tortoises that are actually there, so describing the way detections decrease with distance allows for estimation of the proportion that were present but not detected within a given distance of the transect centerline. Second, an estimate is made of the proportion above ground or visible in their burrows and available to be detected on transects. Third, the first two estimates are combined with the number of tortoises encountered per kilometer walked to provide the actual density in each stratum. Finally, the proportion detected on the line must be estimated. Unless all tortoises were detected on the centerline, the density estimate must be adjusted to account for the occurrence of these additional tortoises.

Separate detection curves were developed for each team. These detection curves will capture any differences between teams in application of the protocol, but are mostly expected to reflect regional differences in terrain as well as the extent to which vegetation obscures the area searched from the transect. In 2008, Kiva crews detected 39% of tortoises within 14 m of the transect centerline, GBI detected 41% within 18 m. In 2009, Kiva crews detected 36% of tortoises within 14 m of the centerline, GBI detected 26% within 15 m. Some of the difference between the two years is probably attributable to drier conditions in 2008 and less spring growth even in shrubs. This is one reason it is helpful to describe detection functions each year and for different parts of the range. Lack of moisture and of spring growth is probably also related to the decreased proportion of tortoises that were visible to be counted (G_0) in 2008 compared to 2009 and most other years. The proportion also varies in different parts of the range, which were surveyed at different times during the spring season. Visibility in 2008 varied from a high of 83% in Coyote Springs during the second half of April and first half of May to 55% at the Chuckwalla telemetry site, monitored in the middle of May. In 2009, the highest proportion visible was 96% at Ord-Rodman in the middle of April, with a low regular season visibility at 64% at Halfway Wash in the last week of April. Although 66% of tortoises were available at the Chuckwalla telemetry site in late April and early May, when the site was visited in the first week of June in conjunction with distance sampling at Chocolate Mountain Aerial Gunnery Range (CMAGR), 58% of tortoises were available. Due to access issues on CMAGR, this site was monitored outside the usual activity period, when lower G_0 estimates are expected.

On average, crews walked 39 km for each tortoise that was observed in 2008, and 36 km in 2009; both of these numbers reflect relatively low encounter rates compared to previous years. In addition, encounter rates varied considerably between monitoring strata. As usual, in 2008 strata in the Northeastern Mojave Recovery Unit had the lowest densities (1.1, 1.2, and 1.9 per km^2, respectively, in the Beaver Dam Slope, Coyote Springs, and Mormon Mesa strata). Forty transects were completed in Gold Butte-Pakoon, but no tortoises were detected, so no density estimate was possible. In fact, at the minimal survey level in 2008, only 3 of the stratum-level estimates are based on detecting at least 10 tortoises. In 2009, with supplemental funding in Nevada, the effort was sufficient to find tortoises in all strata in the Northeastern Mojave; in fact, the density was estimated higher than in the past, at 3.4 tortoises/km^2. Consistent with patterns in the past, the Mormon Mesa stratum had densities about twice as high as the other 3 strata in the recovery unit. Other strata with densities over 7 tortoises/km^2 were Chemehuevi, Chocolate Mountain, Ord-Rodman, and Fenner. Although this program was not developed or designed to accurately estimate annual stratum-level densities, it is informative that the same strata are associated with high and low densities each year. Due to funding limitations, only 12 transects were walked in the BLM portion of Chuckwalla in 2009, but no tortoises were detected there; so there is no density estimate for the Eastern Mojave Recovery Unit that year.

To enable field crews to complete transects in previously un- or under-sampled areas within strata, rules implemented in 2007 required crews to walk the transect in place (no shifting of the transect to a nearby lower-relief area) or determine that it was completely unwalkable. In 2008 and 2009, crews were given more rigid rules for how to modify transects depending on whether obstacles were 1) administrative or infrastructure (roads, private property, etc.) or were 2) related to difficult terrain or substrate. These rules did enable crews to sample entire strata in a more representative way, and enabled us to estimate the proportion of area within each monitoring stratum that cannot be sampled by crews on foot. This allows us to apply the density to a particular acreage and arrive at an estimate of the number of tortoises in the sampled area of each stratum. Because these numbers incorporate uncertainty about the exact acreage that cannot be sampled, the abundance estimates are slightly less precise than the density numbers from which they originate.

During end-of-season debriefings, crew feedback both years showed that the focus on standardized, directed training was valuable to crews. In both years, crews expressed some uncertainty that they were correctly applying protocols for modifying transects. However, weekly written assessments from UNR (2008) and then from USFWS (2009) were able to identify and communicate early in the field season to specific crews about deviations from protocols, so the crews were performing generally better than they perceived. The additional quality control procedures in place resulted in data sets with fewer errors each year compared to any previous years of this program.

Finally, the success of the range-wide monitoring program also depends on developing reliable, adequate, and consistent funding. In 2008, sampling in Gold Butte (40 transects) did not detect any tortoises, and in 2009, with only 12 transects funded in the BLM portion of Chuckwalla, no tortoises were detected there either. Effective implementation of this program requires stable funding so that monitoring effort matches planning requirements rather than funding limitations.

RANGE-WIDE MONITORING OF THE MOJAVE DESERT TORTOISE 2008 AND 2009

INTRODUCTION

The Mojave Desert population of the desert tortoise (*Gopherus agassizii*) was listed as threatened under the Endangered Species Act in 1990. This group of desert tortoises north and west of the Colorado River are now recognized as the species *G. agassizii*, separate from *G. morafkai* south and east of the Colorado River (Murphy et al., 2011). The original (USFWS, 1994) and revised recovery plan (USFWS, 2011) designate recovery units to which decisions about continued listing status should be applied. Because the monitoring efforts reported here preceded the revised recovery plan, data records were associated with the original recovery units so results reported here also use those recovery units. The recovery plan specifies that consideration of delisting should only proceed when populations in each recovery unit have increased for at least one tortoise generation (25 years), and the only means to determine trend is by a rigorous program of long-term monitoring. Before the tortoise was listed, populations were monitored either using strip transects (Luckenbach, 1982) where indications of tortoise presence (live or dead tortoises, scats, burrows, or tracks) were converted to tortoise abundance categories based on transects conducted in areas of better-known tortoise density, or by using capture-recapture population estimates on a limited number of (usually) 1-mi^2 study plots (Berry and Nicholson, 1984). Although data have continued to be collected on transects and study plots in recent years, these methods suffer statistical deficiencies and/or logistical constraints that render them unsuitable for monitoring trends in abundance for entire recovery units (Corn, 1994; Anderson et al., 2001; Tracy et al., 2004). In 1999 the Desert Tortoise Management Oversight Group endorsed the use of line distance sampling (Buckland et al., 2001) for estimating range-wide desert tortoise density.

Distance sampling methods use measurements taken from the center of the transect lines to tortoises to model detection as a function of distance from the walked path; tortoises farther from the travelled path have a lower probability of detection. In order to anchor the curve and estimate the true (not relative) proportion of tortoises detection within a given distance from the center of the transect, all tortoises must be detected on the transect centerline (Anderson et al., 2001; Buckland et al., 2001). There are additional assumptions in distance analysis – that distance is measured to the point where the animal was first detected and that distance is measured accurately – but these are easily satisfied in line distance sampling of desert tortoises. The assumption of perfect detection at the centerline, however, can be violated during line distance sampling of tortoises, so the use of two observers minimizes the probability that tortoises are missed on the centerline. The dual-observer method also provides a correction factor in the form of an estimate of the number of tortoises on the centerline that were missed.

Distance methods have been applied to estimate abundance of Sonoran Desert Tortoises (*G. morafkai*) since 2000 (Swann et al., 2002; Averill-Murray and Averill-Murray, 2005) and in *G. agassizii* in the Upper Virgin River Recovery Unit in Utah since a pilot study in 1997 (McLuckie et al., 2010). The USFWS used line distance sampling to estimate abundance of tortoises in the remaining five recovery units for *G. agassizii* in Utah, Arizona, Nevada, and California starting in 2001 (USFWS 2006 and 2009a). This report includes results of training exercises for field crews, describes implementation of monitoring, and presents separate analysis of desert tortoise density based on data collected in 2008 and 2009.

METHODS

Study areas and transect locations

Long-term monitoring strata will be used over the life of the project to describe population trends in areas managed to conserve tortoises ("tortoise conservation areas," TCAs). Generally each critical habitat unit (CHU) is treated as one monitoring stratum, although the portion of Mormon Mesa CHU that is associated with Coyote Springs Valley is treated as a separate stratum. Chuckwalla CHU is also treated as dual monitoring strata, with potentially unequal sampling effort in the areas managed by the Department of Defense (Chocolate Mountain Aerial Gunnery Range, CMAGR) and by the Bureau of Land Management (BLM). The Piute and Eldorado Valleys are currently treated as one monitoring stratum although they are in different recovery units. The Joshua Tree stratum does not encompass all suitable habitat for desert tortoises in Joshua Tree National Park (JTNP). The national park designation and current boundaries slightly post-date the designation of CHUs, so some of the Pinto Mountains and Chuckwalla CHUs (and monitoring strata) are in the current JTNP.

Figure 1 depicts long-term strata as well as 2 more that were added for 2008 and 2009 only. The Ely Field Office of the Nevada Bureau of Land Management provided supplemental funding in order to develop density estimates in areas just north of the Mormon Mesa and Beaver Dam Slope long-term monitoring strata; these temporary strata are referred to in this report as Mormon Mesa 2 and Beaver Dam Slope 2. Supplemental funding in 2008 from Coyote Springs, Inc. allowed for additional transects in the Coyote Springs stratum. Finally, the USFWS provided additional funding in 2008 in order to sample on public lands in the Pahrump Valley in Nevada. Density estimates for temporary strata are reported here but not included in annual recovery-unit-level estimates that are assessed for long-term trends.

The optimal number of transects in a monitoring stratum was determined by evaluating how these samples would contribute to the precision of the annual density estimate for a given recovery unit. Anderson and Burnham (1996) prepared a power analysis to guide this sort of evaluation for the long-term desert tortoise monitoring project. The power to detect an increasing population size is a function of 1) the magnitude of the increasing trend, 2) the "background noise" against which the trend operates, and 3) the length of time the trend is followed (even a small annual population increase will result in a noticeably larger population size if the increase continues for many years).

The magnitude of the population trend is a function of recovery activities and the population dynamics of the tortoise – neither of these elements are affected by monitoring design and sample size. The second contributor to the power to detect a trend – the level of background variability in the density estimates – is directly affected by the number, length, and placement of transects in the monitoring strata. Anderson and Burnham (1996) recommended that transect number and length be chosen to target precision reflected in a coefficient of variation (CV) of 10-15% for the estimate of importance (here, density over all tortoise conservation areas in each recovery unit). The CV describes the standard deviation (a measure of variability) as a proportion of the mean and is often converted to a percentage. The target CV is achieved based on the number of tortoises that might be encountered there (some strata currently have higher densities than others), as well as the area of the stratum – its proportional contribution to the recovery unit density estimate (Buckland et al., 2001).

The actual number of transects assigned in each stratum was a function of the optimal numbers described above, as well as on available funding. So that recovery unit estimates would be based on the same monitoring areas and therefore comparable between years, a minimum number of transects were placed in each long-term monitoring stratum, then that number was increased up to the optimal level, depending on funding. In 2009, all strata had at least 10 transects, but in 2008, Pinto Mountains and Chemehuevi strata were planned with fewer. This approach to allocating transects in each stratum differed from that in previous years, when the number of assigned transects was proportional to sample area, and strata without dedicated funding were not sampled.

Once the number of transects in a stratum was determined, these were laid out systematically across strata, with a random origin for the lattice of transects. In strata with more assigned transects, nested lattices with smaller spacing (3 km) were used to ensure sufficient transects. In strata with fewer transects, lattices with wider spacing (9- or 27-km spacing) were used. When the number of transects planned for a stratum were not sufficient to use all of the potential sites in the lattice, a subset of the potential sites were selected at random. Use of systematic placement provides more even coverage of the entire stratum, something that may not occur when strictly random placement of transects is used. In both cases, transects are located at random with respect to the location of desert tortoises.

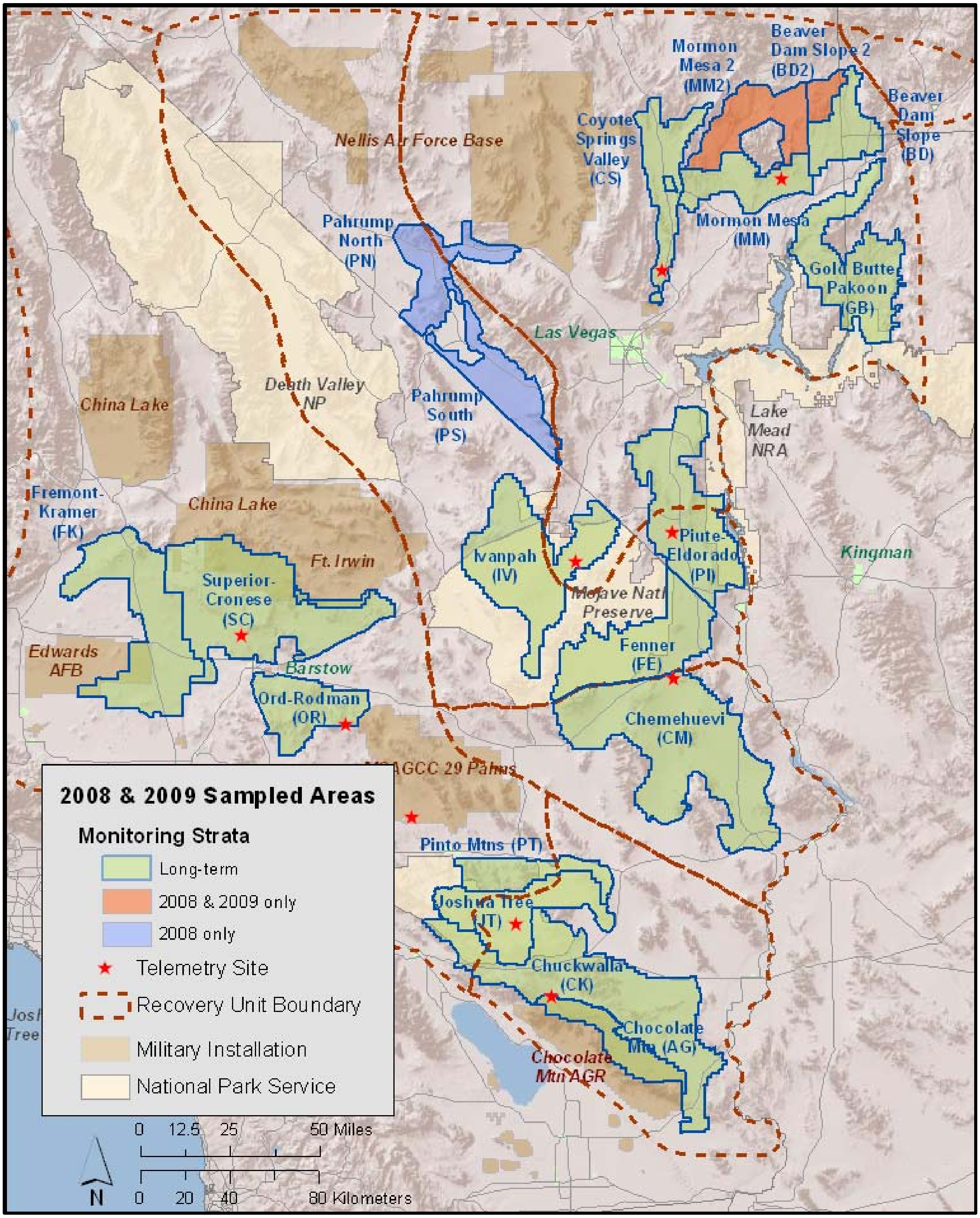


Figure 1. Sampled areas in 2008 and 2009.

Transect completion

One adaptation that tortoises have for living in the desert is to restrict surface activity to fairly narrow windows of time during the year. In general, tortoises predictably emerge from deep within shelters (burrows) from mid-March through mid-May and then again (less predictably) in the fall. These periods coincide with flowering of their preferred food plants (in spring) and with annual mating cycles (in fall). The annual range-wide monitoring effort is scheduled to match the spring activity period for tortoises.

During this season, not all tortoises are above ground or visible in burrows. To encounter as many tortoises as possible, monitoring is scheduled for early in the day and to be completed before the hottest time of day. Because tortoises are located visually, monitoring is restricted to daylight hours. Based on past experience, we expect tortoises to become most active after 7am at the beginning of April (it is usually too cool before this time), but to emerge earlier and earlier until their optimal activity period includes sunrise by the beginning of May. In May, we also expect daytime temperatures to limit tortoise above-ground activity as the morning progresses to afternoon.

Field crews should complete transects during this optimal period each day. Start times were decided a week in advance, so crews arrived at transects at similar times on a given morning. However, completion times were more variable, depending on terrain, number of tortoises encountered, etc. Under normal conditions, each team walked one 12 km square transect each day. Teams were comprised of 2 field personnel who switched lead and follow positions at each corner of each transect, so they each spent an equal amount of time in the leader and follower positions. The leader walked on the designated compass bearing while pulling a 25 m length of durable cord; the walked path was also the transect centerline and was indicated by the location of the cord. When the cord was placed on the ground after a tortoise or carcass was detected, it facilitated measurement of the local transect bearing. The length of cord also spaced the two independent observers, guiding the path of the follower. The walked length of each transect was calculated as the straight-line distance between GPS point coordinates that were recorded at 500 m intervals (waypoints) along the transect and/or whenever the transect bearing changed.

Both leader and follower scanned for tortoises independently without leaving the centerline, and the position of the crew member finding each tortoise was recorded in the data. Although the leader saw most of the tortoises, the role of the follower was to see any remaining tortoises near the centerline, so the follower role is crucial to unbiased estimation of tortoise densities.

Distance sampling requires that distance from the transect centerline to tortoises is measured accurately. When a tortoise was observed, crews 1) used a compass to determine the local transect bearing based on the orientation of the 25 m centerline, 2) used a compass to determine the bearing from the point of observation to the tortoise, and 3) used a measuring tape to determine the distance from the observer to the tortoise. These data are sufficient to calculate the perpendicular distance from the observed tortoise to the local transect line. If the tortoise was outside of a burrow, was handled enough to record mass and midline carapace length (MCL), to determine its sex, and to apply a small numbered tag to one scute. If a tortoise could not be measured because it was in a burrow, because temperatures precluded handling, or for any other reason, crews attempted to establish by other means whether the animal was larger than 180 mm MCL, the criterion for including animals in density estimates.

Modification of previous procedures

Monitoring strata encompass large areas with variable geography and topography. It is expected that tortoises will not occupy any one stratum at a uniform density; some local areas will support higher numbers of tortoises than others. In addition, some of the terrain is so rugged that it would not be safe to complete transects there. From 2001 to 2003, these considerations led planners to mask out some areas of each stratum from sampling (USFWS, 2006). The excluded areas changed in each of these years, however, and for purposes of estimating densities in these strata, more extensive and consistent sampling was desirable. In 2004 and 2005, transects were placed at random on the landscape, with crews able to reflect or to “slide” transects based on safety or other considerations (USFWS, 2006). Examination of completed transects after the field season indicated that many transects were moved for reasons that were unclear – in part because field crews had not documented their decision-making process.

In 2007, a new set of guidelines was provided to crews to give them options for completing transects without moving them away from the basic assigned location. These guidelines (USFWS, 2009) set conditions under which non-standard transects would be created by 1) reflecting transects inward, or 2) creating rectangular transects along obstacles associated with human infrastructure (large roads, private inholdings, etc.). In rugged terrain, 3) transects could be shortened to enable completion before 4pm each day.

Assessment of transect completion in 2007 (USFWS, 2009a) revealed that crews needed more rigid rules for completing non-standard transects; otherwise, different crews might implement very different protocols. In 2008 and 2009, crews had the option to complete transects that were 12 km long (in low-relief terrain) or 6 km long (in higher-relief terrain that precluded completion of 12 km in a working day). In the latter case, to avoid crews selecting particular terrain, the only option for shortening the transect was to walk it in the southwestern quadrant of the intended 12 km square. If the southwestern quadrant was judged too rugged to be completed safely by transect walkers, the final option was to not complete the transect at all. As in previous years, unwalked transects were replaced from the list of randomly ordered alternates. For more detail on field procedures including modification of transect paths, please refer to the *2009 Desert Tortoise Monitoring Handbook* (USFWS, 2009b).

Proportion of tortoises available for detection by line distance sampling, G_0

Although we have general expectations about when tortoises are most active each day, and planned our sampling to match the best season and time of day, basing our density estimates only on the tortoises that were visible would result in density estimates that are consistently underestimated (biased low). Instead, we used telemetry to estimate the proportion of tortoises available for sampling, G_0 ("gee-sub-zero"), which was incorporated in the equation for estimating tortoise density and is used to correct this bias.

Telemetry allows us to locate radio-equipped tortoises that are visible as well as those that are otherwise undetectable in deep burrows or well hidden in dense vegetation. To quantify the proportion that were available for detection ("visible"), telemetry technicians used a VHF radio receiver and directional antenna to locate 8-12 radio-equipped G_0 tortoises in each of eight (2008) or nine (2009) sites throughout the Mojave and Colorado deserts (Fig. 1). One site outside of any monitoring strata (on MCAGGC) was replaced in 2009 by sites in JTNP that were inside a monitoring stratum and already used for separate research. The telemetry site at Halfway Wash in Mormon Mesa was added in 2009.

Each time a transmittered tortoise was located, the observer determined whether the tortoise was visible (*yes* or *no*). Through careful coordination, observers at telemetry sites monitored visibility during the same daily time period when field crews were walking transects in the same region of the desert. Observers completed a survey circuit of all focal animals as many times as possible during the allotted time, recording visibility each time. Bootstrapped estimates of G_0 started by selecting one visibility record at random for each tortoise on each day it was located. The average visibility of all tortoise observations at a site on a given day was calculated and used to estimate the mean and variance of G_0 at that site. When there was more than one site in a given area, the G_0 estimate was calculated as the grand mean of all G_0 sites in the group. One thousand bootstrap samples were generated in PASW Statistics (release 18.0.2; SPSS, Inc., 2 April 2010) to estimate G_0 and its standard error.

Modification of previous procedures

Previous comparison of data collected on transects and at telemetry sites indicated that detection of tortoises in burrows from transect lines may not be proportionate to their actual occurrence in burrows. It has been hypothesized that the search image for burrows may not be similar to that for tortoises, although previous work has concluded that the types of search patterns are compatible (Krzysik, 2002).

Behavioral observers find focal tortoises using radio transmitters, a technique that is very different from the method used to detect tortoises on line transects. For the telemetry observers it is a matter of locating a tortoise (visible or not) after they have determined its general location aurally, whereas transect walkers are not searching with certainty of locating a tortoise – they rely only on visual cues. In 2008, we began collecting additional information on each detected tortoise (at telemetry sites as well as on transects) to describe the numbers of approach angles through which part of the tortoise (or burrow) would have been visible (categorizing this into low, medium, and high visibility) and to describe how obvious the tortoise was in its burrow (low, medium, high). If there is no difference in detectability of tortoises as a function of search image, we expect similar proportions of visible tortoises in each visibility category from transect walkers and from behavior observers. If the odds of being detected differ not only by distance from the line but also a combination of method of detection used (visual or radio receiver), we should be able to describe this difference after a few years of data collection and will be able to modify our calculation of visibility following radio-receiver information to more accurately match the visibility to transect walkers.

Field observer training

Training improvement was a priority in 2008. A set of training modules was adopted during the 2007 field season debriefing. For each module, USFWS worked with University of Nevada, Reno (UNR) researchers and cooperators at USGS to develop training objectives and metrics, and UNR had the lead on developing written training materials. In addition to fundamental changes in the type of instruction provided, field contractor crews were given much more time to practice skills (Tables 1 and 2), including tortoise handling, walking practice transects, and developing detection and distance-measuring techniques on a training course with tortoise models. The monitoring handbook developed in 2008 was comprehensive, so that in 2009, individual chapters were revised as needed and all chapters were posted to the Desert Tortoise Recovery Office website (http://www.fws.gov/nevada/desert_tortoise/reports). The handbook serves as a training manual and as documentation of training that is provided. Starting in 2009, the USFWS assumed responsibility for running the training program.

In 2008 and 2009, two teams of field observers participated. Kiva Biological (Kiva) supplied crews for monitoring in California. Great Basin Institute (GBI) supplied crews for monitoring in Nevada, Arizona, and Utah. Personnel for the former team were mostly trained for the first time in 2008 and returned in 2009. The latter crew was comprised primarily of new personnel each year. Because there were half as many personnel to train, in 2008 the Kiva team began specialized training 5 days after the GBI team (Table 1). However, some of this time was spent working with the team leader for Kiva, who had many previous years of experience with distance sampling. In 2009, due to the experience level of returning Kiva personnel, the GBI crews were provided with 12 full days of preparatory training and practice, whereas the Kiva team was trained for only 5 days (Table 2).

Telemetry training

The primary goal of G_0 training is successful implementation of the G_0 protocol by telemetry crews. This includes correct use of telemetry equipment, understanding G_0 data collection fields, observation of as many radio-equipped tortoises as possible during the day, and covering a window of observation that overlaps the day’s transect observations for each sampling area.

Although all telemetry crews had some prior telemetry experience, performance on this project differs from others that do not require confirmation of the exact location of the tortoise. Unless the exact location is determined, its visibility cannot be accurately recorded. Beyond instruction and testing on use of the equipment in desert terrain, several days of practice were compulsory to be able to troubleshoot locating the tortoise and confirming the location when it could not be seen, In addition, some instruction for telemetry and transect crews overlapped to help each group better understand the purpose their data serve and how the separate data types are related in the final density estimate.

Distance sampling training

Transect walkers were given classroom instruction, field demonstrations, practice transects to complete, and ultimately each team was evaluated based on performance on a field arena outfitted with a high density of polystyrene tortoise models placed in measured locations (Anderson et al., 2001).

Polystyrene models of desert tortoises (“models”) are set out on the training course each year using placement instructions (vegetation or open placement, distance along training line, and distance perpendicular from training line). This course is used to determine whether 1) individual teams are able to detect all models on the transect centerline, 2) whether their survey techniques yield useful detection functions, and 3) whether they can accurately report the distance of each model from the transect centerline. For each purpose, many opportunities must be provided, so the course is populated at a very high density of models (410/km^2).

In December 2008, it was discovered that the original training course had been tampered with. A new course was set out in a different location. The same procedures were used to determine placement of models in the new course; however, the detection patterns were expected to differ between 2008 and 2009 due to sparser vegetation and different substrate at the new site.

Crews were sent on transects and training lines as paired, independent observers. That is, the follower was 25 m behind the leader, with the opportunity to detect models not found by the leader. If the leader detects 80% of all tortoises that are found, it is assumed that the follower detects 80% of the tortoises that are missed by the leader. If this assumption is true, in this example, the pair together will detect 0.80 + (0.80 X (1 – 0.80)) = 0.96 of all tortoises on the centerline. Because the location of all models was known, data from training lines were also used to 1) assess the dual-observer assumption that all models were equally detectable (detections attributed to the follower occur at the same rate as original detection rate by leader), and 2) to estimate the detection rate using this technique for tortoises elsewhere in the Mojave Desert. These data on models were used to evaluate and correct crew performance before the field season, but were not used in any way to estimate densities of live tortoises once field surveys began.

Table 1. Training schedule for 2008.

	GBI trainees		Kiva Trainees	
Date	**Activity**	**Trainer**	**Activity**	**Trainer**
Week 1				
10-Mar	Desert Tortoise Recovery and Monitoring Program Working on Public Lands Introduction to Line Distance Sampling & "G_0" Protocols for non-standard transects	Allison (FWS) Ronning (BLM) Corn (USGS) Allison		
11-Mar	Tortoise biology and handling lecture/practice	Christopher (GBI)		
12-Mar	Transect methods lecture Compass/GPS use for line distance sampling Field: Compass/GPS Exercise	Corn Heaton (UNR) Heaton		
13-Mar	Training line lecture Equipment and Database Lecture/Exercises	Corn Heaton/Patil		
14-Mar	Training Lines (practice, 8km) QAQC Specialist Training	Corn/Allison Heaton		
Week 2				
17-Mar	Training Lines (practice, 8km)	Allison		
18-Mar	Training line debriefing Tortoise Handling Tortoise and burrow visibility training	Allison /Corn Christopher Allison		
19-Mar	Practice transects (8km) G_0 instruction on-site QA/QC specialist training	Team leaders Essary (GBI) Heaton/Patil	Desert tortoise recovery and monitoring Introduction to Line Distance Sampling & "G_0" Protocols for non-standard transects Equipment and database lecture and exercises Transect methods Compass/GPS use for line distance sampling Training line lecture QA/QC specialist training	Allison " " " Pavliscak (Kiva) " " Heaton/Patil
20-Mar	Practice transects (8km) + G_0	Team leaders	Tortoise biology and handling lecture/practice	Woodman (Kiva), Pavliscak, Christopher
21-Mar	Training Lines (evaluation, 8km)		Practice transects (6km) Field: Compass/GPS Exercise	Pavliscak

	GBI trainees		Kiva Trainees	
Date	**Activity**	**Trainer**	**Activity**	**Trainer**
Week 3				
24-Mar	Training Lines (evaluation, 8km)		Training Lines (practice, 4km)	Allison
25-Mar	Practice transects (12km) + G_0		G0	Pavliscak
26-Mar			Training lines (Evaluation, 8km)	Allison
27-Mar	Final electronic delivery of QA/QC'd training data		Training lines (Evaluation, 8km)	Allison
28-Mar			Practice transects (12km) incl. G_0 and QA/QC	Pavliscak
29-Mar			Practice transects (12km) incl. G_0 and QA/QC Final electronic delivery of QA/QC'd training data	Pavliscak

Table 2. Training schedule for 2009.

	GBI		Kiva	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**
WEEK 1				
Monday, 16-Mar	Transect methods lecture 6km transects	Allison/ Experienced crews		
Tuesday, 17-Mar	Introductions and DT Recovery/Monitoring Programmatic Overview Distance Sampling Tortoise Activity/G_0 Working on Public Lands Transect methods lecture Non-standard transects RDA/BT GPS, Pendragon Database Lecture and Exercises Quality control procedures for field crews Compass/GPS Lecture	Allison “ “ BLM Districts Allison “ Patil Allison, Learmont, Patil Allison		
Wednesday, 18-Mar	Tortoise biology and handling instruction Tortoise handling and data collection - small groups Pen search image exercise (with RDA) Training line lecture & crew quality control procedures Compass/GPS Exercise Data transfer and QA/QC (for specialists)	DTCC Staff DTCC Staff “ Allison/ Brenneman Allison Patil, Learmont		
Thursday, 19 March	Training Lines (practice, 8km) Begin data download from RDAs	Allison		
Friday, 20-Mar	Training Lines (practice, 8km) G_0 Initial QAQC (QAQC specialists only)	Sparks Brenneman		

	GBI		Kiva	
Day/Date	**Activity**	**Trainer**	**Activity**	**Trainer**
WEEK 2				
Monday, 23-Mar	Full transects (12km) (half crew) G_0 / activity observation (half crew)	 Sparks		
Tuesday, 24-Mar	Tortoise handling Pen search image exercise Training line debriefing	Staff “ Allison		
Wednesday, 25 Mar	Training Lines (evaluation, 8km)		Practice 8- or 12-km transects Data transfer and QA/QC	
Thursday, 26 Mar	Training Lines (evaluation, 8km)		Updates for 2009 (see material for GBI trainees, 17 March)	Allison
Friday, 27 March	Full transects (12km) (half crew) G_0 / activity observation (half crew)	 Sparks	Training Lines (evaluation, 8km)	Allison
WEEK 3				
Monday, 30-Mar	Tortoise handling Compass navigation exercise Training line debriefing	Staff Allison	Training Lines (evaluation, 8km)	
Tuesday, 31-Mar	Full transects (create non-standard) or repeat training lines as needed G_0		Training lines debriefing Tortoise handling	Allison Staff
Wednesday 1-Apr	*Begin field data collection*		*Begin field data collection*	
Thursday, 2April	Deliver QA/QC’d data from practice transects		Deliver QA/QC’d data from practice transects	

Data management including quality assurance and quality control

Two sets of data tables were maintained through the field season, organizing data collected on transects and at the G_0 sites. Collection data forms, sheets, applications, and databases are designed to minimize data entry errors and facilitate data verification and validation. Data were collected in both electronic and paper formats by the two survey organizations, then combined and processed in a series of phases to create final database products. Data quality assurance and quality control (data QA/QC, also known as verification and validation) is performed during the data collection, data integration, and data finalization phases. During the second, data integration phase, after combining data from separate groups, some attribute fields are added and all fields are formatted for final processing. The third phase, data finalization, involves consolidation, resolution of data inconsistencies, and generation of final spatial and non-spatial data products. After data analysis and reporting are completed, electronic data are actively hosted for download from the internet through http://www.mojavedata.gov/deserttortoise_gov/recovery/data.php. Figure 2 describes the overall data flow.

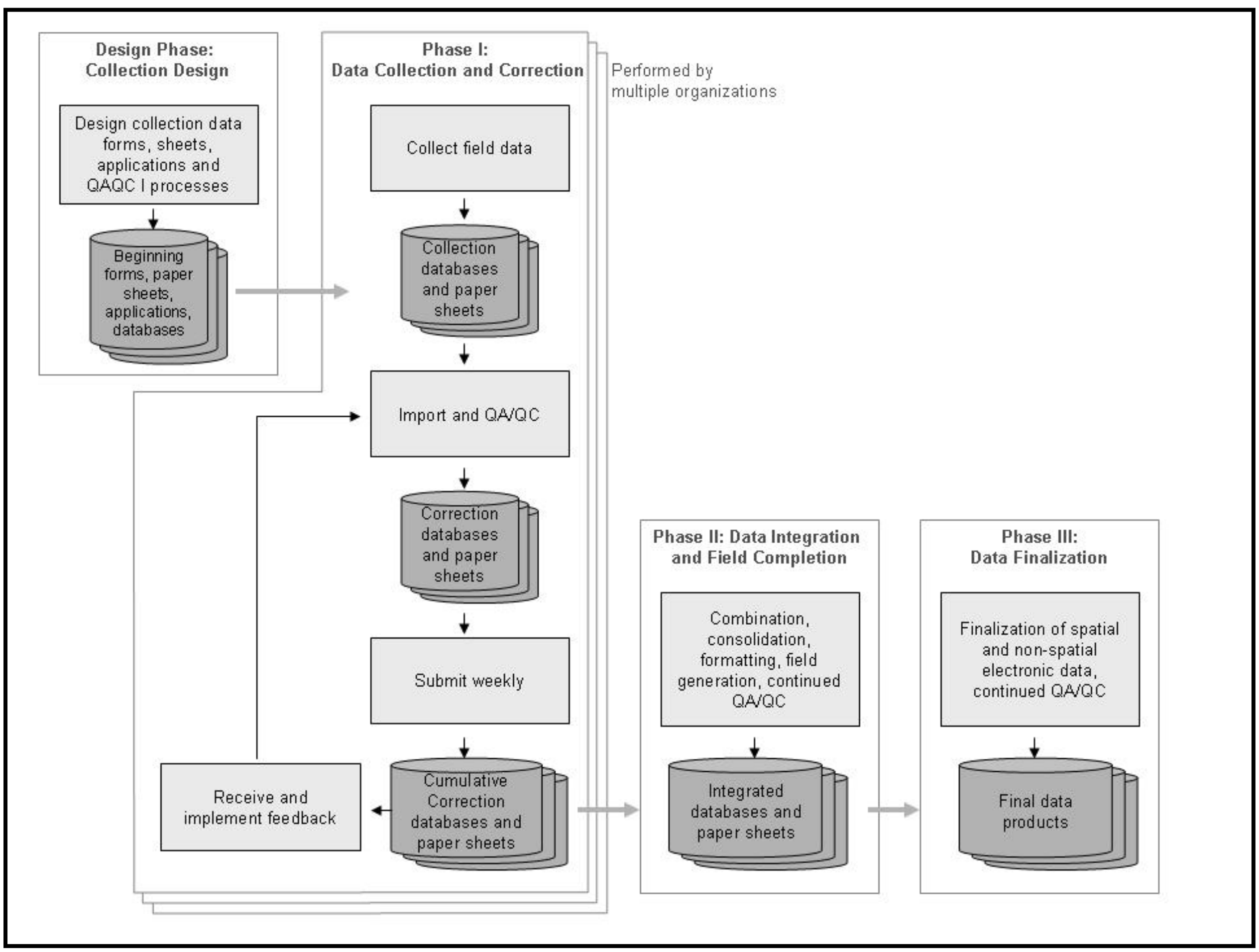


Figure 2. Data flow from collection through final products.

Tortoise encounter rate and development of detection functions

The number of tortoises seen in each stratum and their distances from the line are used to estimate the encounter rate (tortoises seen per kilometer walked), the detection rate (proportion of available tortoises that are detected out to a certain distance from the transect centerline), and their respective variances. Detection function estimation is "pooling robust" under most conditions (Buckland et al., 2001). This property holds as long as factors that cause variability in the curve shape are represented proportionately (Marques et al., 2007). Factors that can affect curve shape include vegetation that differentially obscures vision with distance, and any differences between individual crews (pairs) in how they search for tortoises. The number of transects completed by a field team (GBI or Kiva) typically differs between teams and by the same team in different years. For this reason, after the field season I expected to develop at least one curve for each field team, which also corresponds to different regions of the desert. The encounter rate is less sensitive to small sample sizes, so it was estimated for each stratum separately.

I used Program DISTANCE, Version 6, Release 2 (Thomas et al., 2010) to fit appropriate detection functions, to estimate the encounter rate of tortoises in each stratum, and to calculate the associated variances. One record was created for each transect, with additional records for each additional tortoise on that transect. Analysis was applied to all live tortoises larger than 180 mm MCL. Transects were packaged into monitoring strata ("regions" in Program DISTANCE).

I truncated observations to improve model fit as judged by the simplicity (reasonableness) of the resulting detection function estimate (Buckland et al., 2001). Using truncated data, I used the Akaike Information Criterion (AIC) to compare detection-function models (uniform, half normal, hazard-rate, and negative-exponential) and key function/series expansions (none, cosine, simple polynomial, hermite polynomial) recommended in Buckland et al. (2001).

Proportion of available tortoises detected on the transect centerline, *g(0)*

Transects were conducted by 2-person crews using the method adopted beginning in 2004 (USFWS, 2006). Transects were walked in a continuous fashion, with the lead crew member walking a straight line on a specified compass bearing, trailing about 25 m of line, and the second crew member following at the end of the line. This technique involves little lateral movement off the transect centerline, where attention is focused. Use of two observers allows "removal" type estimation of the proportion of tortoises detected on the line; this provides a test of the assumption is that all tortoises on the transect centerline are recorded ($g(0) = 1$). The capture probability (p) for tortoises within increasing distances from the transect centerline was estimated as for a 2-pass removal estimator (White et al., 1982): p = (lead–follow)/lead, where lead = the number of tortoises first seen by the observer in the leading position and follow = the number of tortoises seen by the observer in the follower position. The corresponding proportion detected on the line by two observers was estimated by $g = 1 - q^2$, where $q = 1 - p$. Figure 4 graphs the relationship between the single-observer detection rate (*p*) and the corresponding dual-observer detection rate (*g(0); "gee at zero"*). The actual proportion detected can be estimated, but to avoid the necessity of compensating for imperfect detection, during training field crews (pairs) are expected to detect 96% of all models within 1 m of the transect centerline. This corresponds to the leader being responsible for at least 80% of the team's detections near on the centerline in order to meet this standard (Fig. 3) and is the basis for one of the training metrics (see Table 4).

Few or no tortoises are located exactly on the line, and even examining a small interval (such as 1 m on each side of the transect line) results in few observations to precisely estimate *g(0)*. Instead, my test of the assumption involves examination of the lead and follow proportions starting with counts of tortoises in larger intervals from the line, moving to smaller intervals centered on the transect centerline. As the intervals get smaller the sample sizes also get smaller, but the estimates are more relevant to the area right at the transect centerline. The expectation is that the estimates should converge on *g(0)* = 1.0.

If the test does not indicate that all tortoises were seen on the transect centerline, the variance of *p* can be estimated as the binomial variance = $q(1 + q)/np$, where n = the estimated number of tortoises within 1 m of the transect centerline, and the variance of *g(0)* is estimated as twice the variance of *p* (White et al., 1982).

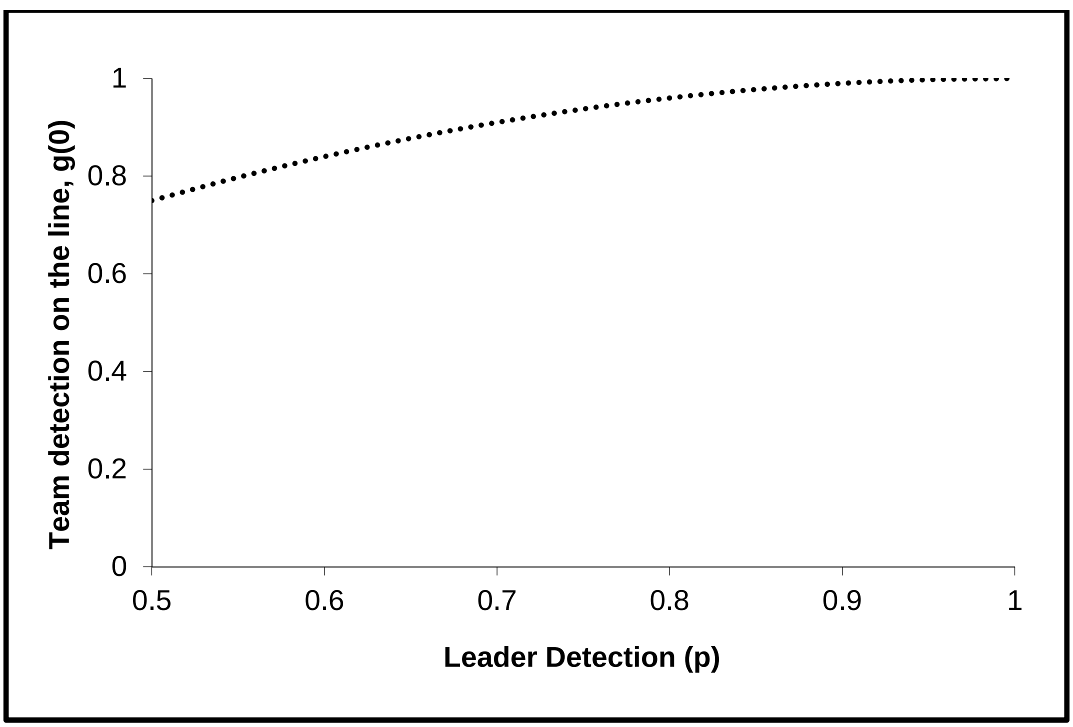


Figure 3. Relationship between single-observer detections (by the leader) and dual-observer (team) detections.

Estimates of tortoise density

Each year, the density of tortoises is estimated at the level of the recovery unit. The calculation of these densities starts with estimates of the density of tortoises in each stratum from Program DISTANCE, as well as their variance estimates:

$$D = \frac{n}{2wLP_a G_0 g(0)},$$

where L is the total length of kilometers walked in each stratum and w is the distance to which observations are truncated, so $2wL$ is the area searched in each stratum. This is a known quantity (not estimated). P_a is the proportion of desert tortoises detected within w meters of the transect centerline and was estimated using detection curves in Program DISTANCE. The encounter rate (n/L) and its variance were estimated in Program DISTANCE for each stratum. Calculation of D requires estimation of n/L, P_a, G_0, and $g(0)$. This means that the variance of D depends on the variance of these quantities as well.

For desert tortoise densities, the encounter rate (n/L) is estimated independently for each stratum, whereas proportion of available tortoises and proportion of available tortoises detected on the transect centerline are estimated jointly for all strata ($g(0)$) or for all strata in the recovery unit (G_0). The detection function, which comes into the above equation as P_a, may be estimated jointly for all observations or separately for observations from each field team, depending on the number and quality of observations. In 2008 and 2009, separate detection curves were created for each field team (GBI and Kiva), pooled across all strata surveyed by that team. A schematic of the process leading to density estimates is given in Figure 4. Contributing estimates in the four left-hand columns are listed with the subsets of the data on which they are based. These estimates combined from left to right to generate stratum and recovery unit density estimates. Estimates from Beaver Dam Slope 2, Mormon Mesa 2, and Pahrump North and South strata are not part of the long-term monitoring project and are not used to develop annual recovery-unit-level density estimates.

Whereas the number of tortoises in the set of strata representing a recovery unit can be simply added together, the variance must be arrived at by accounting for whether this involves pooled or unpooled estimates. As described above, three of the four estimates that contribute to calculating density in a stratum were based on data “pooled” from other strata as well, so when data from these strata are combined, the correlated nature of the variances has to be accounted for. Specifically, the method described in Buckland et al. (2001:89) was used to combine density variances correctly and arrive at the variance (and confidence intervals and CV) for the recovery unit. Pooled and unpooled variance estimates cannot currently be combined as needed in Program DISTANCE, so final construction of density mean and variance estimates from the above components was completed without specialized software.

Tortoise encounter rate	Proportion that are visible, G_0	Detection rate, P_a	Proportion seen on the line, $g(0)$	Density	Density
Stratum	*Regionl G_0 sites*	*Field team*	*Overall*	*Stratum*	*Recovery unit*
FK	Ord Rodman + Superior-Cronese	Kiva	Full set of tortoise observations	FK	Western Mojave
SC				SC	
OR				OR	
JT	MCAGGC + Chuckwalla			JT	
PT				PT	
CK				CK	Eastern Colorado
AG	Chuckwalla			AG	
CM	Piute + Ivanpah + Chemehuevi			CM	Northern Colorado
FE				FE	Eastern Mojave
IV				IV	
PI		GBI		PI	
BD	Coyote Springs through 13 May			BD	Northeastern Mojave
GB				GB	
CS				CS	
MM				MM	
MM2				MM2	
BD2				BD2	
PN	Coyote Springs after 13 May			PN	
PS				PS	

Tortoise encounter rate	Proportion that are visible, G_0	Detection rate, P_a	Proportion seen on the line, $g(0)$	Density	Density
Stratum	*Regional G_0 sites*	*Field team*	*Overall*	*Stratum*	*Recovery unit*
AG	Chuckwalla (June)	Kiva	Full set of tortoise observations	AG	Eastern Colorado
CK	Joshua Tree + Chuckwalla (pre-June)			CK	
JT				JT	Western Mojave
PT				PT	
FK	Superior-Cronese + Ord Rodman			FK	
OR				OR	
SC				SC	
CM	Chemehuevi + Ivanpah + Piute			CM	Northern Colorado
FE				FE	Eastern Mojave
IV				IV	
PI				PI	
CS	Coyote Springs	GBI		CS	Northeastern Mojave
BD	Halfway Wash			BD	
GB				GB	
MM				MM	
MM2				MM2	
BD2				BD2	

Figure 4. Process for developing density estimates in 2008 (top) and 2009 (bottom). Stratum abbreviations as in Fig. 1

Area of each stratum sampled and the number of tortoises in that area

Before the 2008 field season, based on experience in 2007 and visual examination of DEM overlays, all assigned transects were classified as possible for completion as 12k square, 6k squares, or as unwalkable. These classifications before the field season were advisory only, because exact ground conditions, weather, and crew condition all affect the ability to complete a transect. If a non-standard transect (not 12 km square) is walked, crews indicated the obstacles they encountered that forced the change in protocol. In addition to the above named factors, substrate that is very loose on a steep slope or that includes large boulders could make progress so slow or treacherous that crews modified the transect.

In 2008 and 2009, some transects were repeated from the previous year(s), providing new information on ground conditions, and new transects were attempted. At the end of each field season, transects that were not completed as expected were reevaluated, possibly resulting in reclassification of the transect. The classification was used to advise future transect completion, but also to estimate the proportion of each monitoring stratum that is actually represented by the walked transects. These steps were repeated through 2011, so the updated proportions through December 2011 are reported here and used to estimate abundance in walkable areas of each stratum.

Because each transect of any length was built off of the southwestern corner, how that transect was completed is one representation of transects built on all possible southwestern corners. In order to avoid selection bias by crews, there were only 3 classification options for entire transects, so that only 0-, 6-, or 12-km were actually walked, but of course all of the distances between these options might actually have been walkable. Transects that were not walked represent all transects that could be walked for lengths of 0- to 6-km. It is parsimonious to therefore assume that on average, 3 km could have been walked for each transect classified as "unwalkable." Transects completed using the 6 km option represent all of those that could have been completed for distances of 6- to 12-km, averaging 9 km, so that is the expected value for all of those transects. Transects completed as 12 km represent the 100% completion option. The total area of the stratum that is unwalkable is estimated as:

$$Proportion\ unwalkable = \frac{0.25(\#\ 6k\ transects) + 0.75(\#\ unwalkable\ transects)}{\#\ transects\ classified\ since\ 2008}.$$

If a given stratum covers 5000 km^2, but only 90% was walkable and represented by our sampling design, then the density estimate applies to 4500 km^2, and can be used to generate an estimate for the number of tortoises in those 4500 km^2. Using these area estimates adds another source of imprecision, so abundance estimates are slightly less precise than the density estimates from which they were derived. The additional error of this estimate is calculated as the error for a binomial proportion.

Debriefing to describe strengths and weaknesses of project preparation and execution
At the end of each field season, a debriefing meeting was held to review tasks and responsibilities, strengths and weaknesses of the program, and to plan for the next field season. Because the field teams had disbanded by then, field crew members were surveyed prior to the end of the field season to nonetheless gather their direct input as we identified training and logistical issues to target for improvement before the next field season. Although issues and/or tasks may be ascribed to individual entities, this meeting is most beneficial in identifying where centralized and/or coordinated response is required to improve the quality of the program.

RESULTS

Field observer training
In 2008, crew trials were conducted for GBI trainees on 21 and 24 March (Table 1). Kiva's crews walked their trials on 26 and 27 March. In 2009, crew trials were conducted for GBI trainees on 25 and 26 March (Table 2). Kiva's crews walked their trials on 27 and 28 March. In this case, most Kiva crews were comprised of returnees from 2008, so the comparison in this report is between first-year (GBI and some Kiva) or returning (most Kiva) crews.

Crews in 2009 performed better than in 2008. This may reflect the more open terrain for the training lines as well as a change in oversight that required crews to pass predetermined benchmarks. In 2009, a new database was used to provide trainees with comprehensive next-day feedback based on their practice trial. This type of feedback was more difficult to provide in earlier years and was not available in comprehensive form in 2008. Using the 2009 feedback system, USFWS worked with individual pairs to modify their search patterns based on the initial trial.

Proportion of tortoises detected at distances from the transect centerline
Tables 3 and 4 report the proportion of models that were available and were detected by each team at 1-, 2-, and 5-m from the transect centerline in 2008 and 2009, respectively. Detection on the centerline was expected to be 100%, and most crews achieved this in 2009, but achievement was extremely variable in 2008 and in fact the team averages were well below the standard. Although the arena was moved to a less-vegetated area in 2009, it is likely that most of the apparent performance differences actually reflect the fact that training data were not subjected to post-collection QA/QC or to immediate evaluation in 2008 (detection curves were reviewed, however). This is very different from 2009, when misidentified and misplaced models could be identified and field-verified immediately. In 2008, there were 67 reports of models more than 10 m from their expected placements; these would all have been corrected in subsequent years, but for 2008 the records cannot be repaired. Failing these corrections, the 2008 summaries will imply worse performance than was achieved. In 2009, most of the Kiva crew was returning. First-year trainees (mostly GBI) detected a similar proportion of models at 1- and 2 m compared to experienced crews, with first-year trainees detecting fewer models at 5 m. As long as all tortoises

models within a meter of the center are detected, the specific pattern 5 m detections is not of consequence.

Table 3. Proportion of tortoise models detected by teams in 2008 within 1-, 2-, or 5-m of the transect centerline.

	Proportion of existing models within a given distance and were detected by the team		
Team	1m	2m	5m
1	0.69	0.67	0.73
2	0.92	0.75	0.69
6	0.85	0.79	0.78
7	0.71	0.70	0.71
8	0.69	0.79	0.71
9	0.92	0.89	0.82
10	0.77	0.68	0.71
11	0.79	0.81	0.70
12	0.62	0.70	0.58
13	0.54	0.70	0.63
17	0.77	0.70	0.71
18	0.62	0.71	0.63
22	1.00	0.79	0.71
23	0.29	0.43	0.69
24	0.75	0.80	0.81
31	0.69	0.75	0.77
32	0.69	0.70	0.76
33	0.93	0.92	0.87
34	0.92	0.85	0.81
35	0.77	0.81	0.84
36	0.71	0.74	0.79
Kiva	0.79	0.80	0.81
GBI	0.73	0.73	0.71
Overall	0.74	0.75	0.74
Gray-highlighted cells indicate sub-standard results			

Table 4. Proportion of tortoise models detected by teams in 2009 within 1-, 2-, or 5-m of the transect centerline.

	Proportion of existing models within a given distance and were detected by the team		
Team	1m	2m	5m
1	1.00	0.96	0.89
2	1.00	0.96	0.88
3	1.00	0.96	0.94
5	1.00	0.96	0.86
7	1.00	1.00	0.90
8	0.94	0.86	0.86
9	0.93	0.92	0.89
10	1.00	1.00	0.91
11	1.00	1.00	1.00
12	0.85	0.93	0.88
13	1.00	0.93	0.89
14	1.00	1.00	0.95
15	1.00	0.93	0.89
16	1.00	0.96	0.87
17	1.00	0.89	0.94
18	1.00	0.93	0.91
41	1.00	0.92	0.97
42	1.00	1.00	0.98
43	1.00	1.00	0.98
44	0.93	0.96	0.96
45	1.00	1.00	0.94
46	1.00	0.96	0.89
47	1.00	1.00	1.00
48	1.00	1.00	0.97
Returning crews	**0.99**	**0.98**	**0.96**
First-year crews	**0.98**	**0.95**	**0.90**
Overall	**0.99**	**0.96**	**0.92**
Gray-highlighted cells indicate sub-standard results			

Tables 5 and 6 report further statistics for each team after collecting data on 16 km on the evaluation lines. Measurement accuracy reported in these tables gives the average absolute difference between the expected and measured perpendicular distances from the model to the walked line. All measurements for all models during the 2-day trial are used for this estimate, and capture inaccuracies from 1) using a compass and measuring tape to record distances to the models, plus 2) inaccurately following the trajectory of the transect. The latter source of error does not occur on monitoring transects, because the walked transect is the true transect. In contrast, on training lines, error in measurements is increased if crews do not walk on exactly the measured line that was used to place the models. On average, the measured distance of models to the centerline was 17 cm farther than the actual distance in 2008, and 19 cm closer in 2009. The bias increased for models farther from the line. The “Available Models Detected by Leader” column reports the proportion of all models that were found first by the leader. During training, this number is easily calculated and is used to identify crews in which one of the observers is not finding at least 80% of all detected. With an 80% detection rate for the leader, a 96% detection rate is expected for the team. The relatively low leader detections seen in 2008 are associated with the underestimates of tortoise model abundance on the right side of the table. These estimates assume that all models were detected on the centerline, although with the models, we are aware that many were missed. The high proportion of leader detections in 2009 is likewise associated with better accuracy in estimating the overall density of models that year.

Table 5. Diagnostics for individual teams after training in 2008.

Team	Available models detected by leader		Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
	Within 1m of centerline	Within 2m of centerline			Lower limit	Upper limit
1	0.69	0.63	1.33	366	293.7	456.6
2	0.92	0.71	1.27	395	314.0	497.6
6	0.77	0.57	1.53	367	298.3	450.3
7	0.64	0.67	1.66	356	287.4	442.1
8	0.69	0.79	1.10	326	257.9	411.3
9	0.77	0.78	1.33	393	308.5	500.0
10	0.69	0.61	1.06	368	299.0	452.4
11	0.71	0.78	0.91	298	232.9	381.2
12	0.38	0.56	1.69	226	185.7	276.0
13	0.46	0.63	1.34	249	181.3	341.8
17	0.69	0.59	0.96	326	261.5	405.8
18	0.54	0.64	1.31	311	248.7	390.1
22	1.00	0.79	1.10	380	257.4	561.0
23	0.29	0.36	1.05	327	234.3	455.5
24	0.63	0.73	0.97	327	248.6	429.6
31	0.69	0.75	1.00	402	323.8	497.9
32	0.69	0.67	0.88	361	292.9	445.7
33	0.71	0.81	0.92	396	324.2	484.5
34	0.85	0.78	1.00	372	305.1	454.4
35	0.69	0.74	0.92	418	335.0	522.5
36	0.71	0.70	0.86	408	335.8	496.0
Target	**>0.80**	**>0.70**	**<1**	**410**		
GBI crews	**0.73**	**0.74**	**0.93**	**334**		
Kiva crews	**0.66**	**0.66**	**1.24**	**393**		
Overall	**0.68**	**0.68**	**1.15**	**351**		

Gray-highlighted cells indicate sub-standard results

Table 6. Diagnostics for individual teams after training in 2009.

Team	Available models detected by leader		Measured v. exact model distance (m)	Estimated abundance	95% confidence interval	
	Within 1m of centerline	Within 2m of centerline			Lower limit	Upper limit
1	0.93	0.92	0.92	439	361.8	533.9
2	1.00	0.89	0.91	407	294.0	563.4
3	0.93	0.93	0.62	463	383.1	558.9
5	1.00	0.93	1.21	384	304.6	482.9
7	1.00	0.96	0.79	387	286.4	523.1
8	0.88	0.79	0.94	407	338.5	488.4
9	0.73	0.77	0.93	395	292.8	532.9
10	1.00	1.00	0.79	437	330.0	578.3
11	0.93	0.97	0.73	514	460.0	573.3
12	0.85	0.89	0.94	455	380.2	543.8
13	0.92	0.85	0.87	391	270.6	564.0
14	1.00	1.00	0.63	500	441.7	566.3
15	0.92	0.82	0.80	467	411.3	530.5
16	0.93	0.93	0.78	432	353.8	527.0
17	0.92	0.82	0.87	430	365.5	506.5
18	0.93	0.89	1.05	376	294.3	480.7
41	1.00	0.92	0.69	506	400.9	639.4
42	0.86	0.93	0.76	472	419.7	531.5
43	1.00	1.00	0.62	435	331.0	572.9
44	0.93	0.96	0.69	480	399.5	575.8
45	0.85	0.89	0.82	502	422.9	595.8
46	1.00	0.96	0.67	416	274.1	631.3
47	0.83	0.93	0.78	464	404.4	532.1
48	1.00	1.00	0.78	498	421.8	588.5
Target	**>0.80**	**>0.70**	**<1**	**410**		
Returning crews	**0.93**	**0.95**	**0.73**	**472**		
First-year crews	**0.93**	**0.91**	**0.86**	**430**		
Overall	**0.94**	**0.92**	**0.82**	**444**		
Gray-highlighted cells indicate sub-standard results						

Figure 5 through Figure 8 are detection curves for crews that remained together into the field season. Interpretation is provided for Figs. 7 and 8, which were used by the USFWS to diagnose and correct search patterns in 2009. Curves for first-year trainees in 2009 (Fig. 7) were generally well-shaped, although one of the curves (for Team 13) had more than one inflection and generally too many detections farther from the line. This team went through an additional test after consulting on ways to improve the curve.

Perhaps more surprisingly, the experienced teams had more difficulty maintaining the correct search pattern to develop an appropriate detection curve. In Fig. 8, the three upper-most curves correspond to teams 41, 43, and 48. As indicated in Table 6, these teams had perfect detection of models on the centerline, but team 48 had a very inaccurate final population estimate, and all three teams had unusually wide confidence intervals for this estimate. These issues arise when the deflection points of the detection curve are difficult to model (less precision), so all three teams had to adjust their search patterns to concentrate closer to the centerline before the field season started. Among the first year trainees (Fig. 7), Teams 7 and 9 also were tested with a wide detection shoulder. Team 7, like the experienced teams, detected all models on the centerline. Their overall estimate was therefore accurate, but the density estimate was imprecise, reflected in a very wide confidence interval. Team 9 did not have perfect detections on the centerline, so their task was to spend relatively more of their time searching near the line.

Within the set of teams with appropriate search patterns, there was considerable variability in the shapes of these curves, and strikingly different detection curves represent different detection probabilities (P_a). Detection curves that fall more rapidly after the first few meters generally indicate more appropriate search patterns, with more attention near the transect centerline. Distance sampling and development of a single detection curve from many observers is nonetheless robust to the effects of pooling these differences, as long as the observers contribute equally to the overall pattern (Marques et al., 2007) by walking the same number of transects.

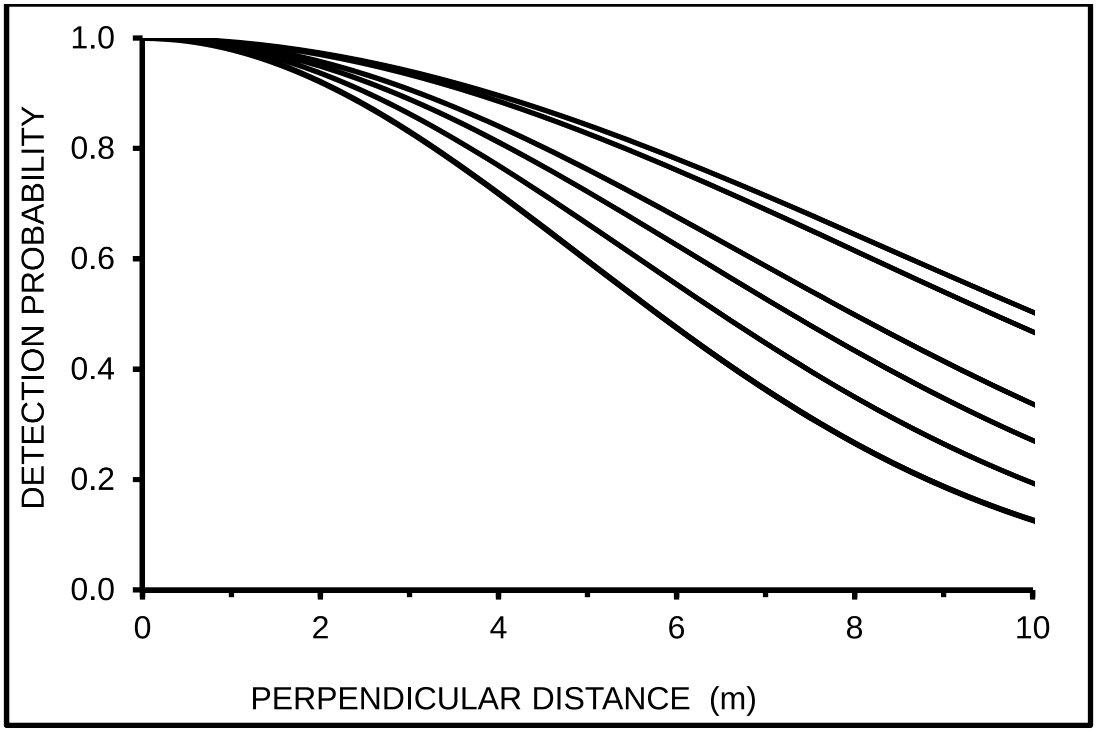


Figure 5. Training detection curves for Kiva crews in 2008. Curves are based on 16 km trials with approximately 100 detections.

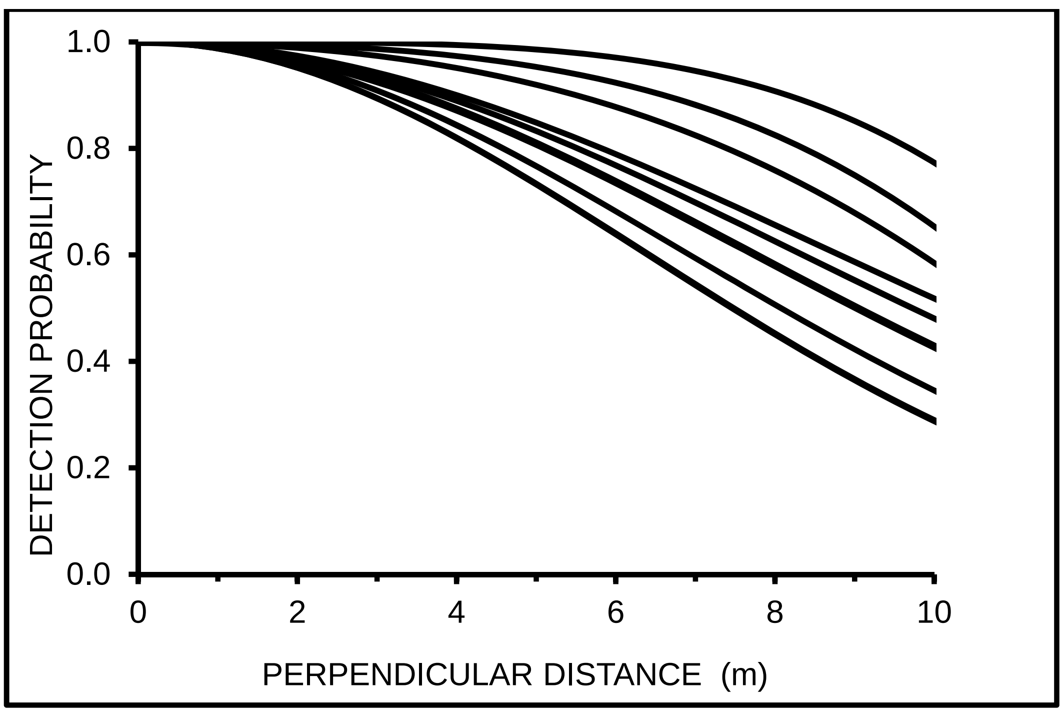


Figure 6. Training line detection curves for GBI in 2008. Curves are based on 16 km trials with approximately 100 detections.

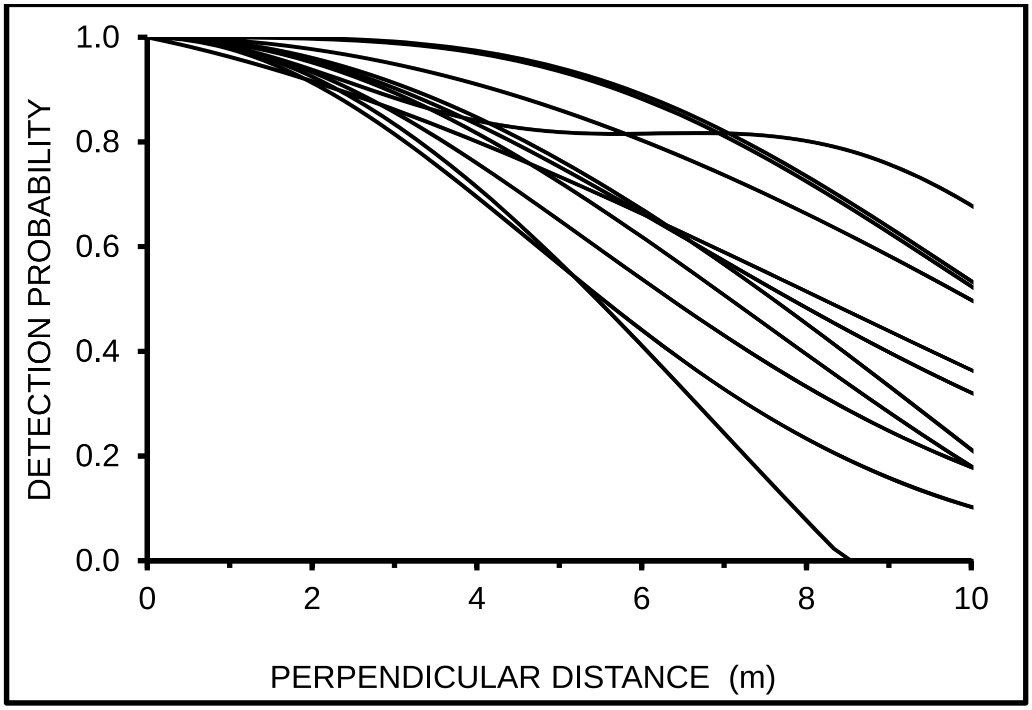


Figure 7. Detection curves for each of the 2009 first-year teams that were kept together into the field season. Curves are based on 16 km trials with approximately 100 detections.

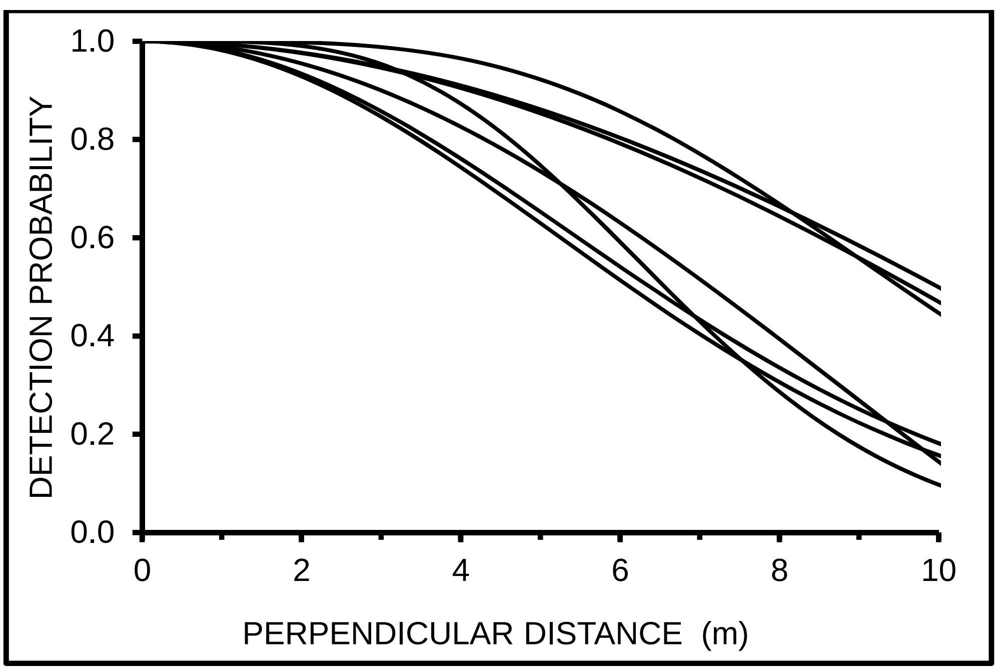


Figure 8. Detection curves for each of the 2009 trainee teams that returned after at least one year of monitoring experience. Curves are based on 16 km trials with approximately 100 detections.

Quality assurance and quality control

There were 21,208 transect records and 4322 G_0 records associated with the monitoring effort in 2008. After data specialists with the field teams had finished verifying and validating the data, there were still 1212 cases where the data were inconsistent with constraints and expectations. (Note that many more issues are addressed each year by data specialists for field crews before the field data are submitted.) Of these, 978 were errors created by the field crews (sometimes faulty equipment, other times data entry error). Another 158 were checked and found to be correct but extreme values. Finally, 76 errors were "processing" errors. Processing steps are associated with correcting other errors (perhaps a word is misspelled) or with adding new fields, or any other manipulation that occurs after the data have been collected. When there are pages missed when paper datasheets are scanned, this is a processing error.

In 2009, the larger field effort is reflected in the increased number of records (22,884 transect records and 4413 from G_0 observations). Overall, 1593 inconsistencies were addressed after field teams had finished verifying and validating their data. Of these, 945 were errors generated by faulty data entry or faulty equipment. Possibly due to enhanced crew and specialist training, there were fewer data entry errors than in 2008. Possible due to aging electronic equipment, there were more equipment errors.

Of the inconsistencies identified in 2009, 350 were verified to be correct but extreme or unexpected entries. These are not errors and no correction was necessary. There were many more processing errors in 2009 than in 2008 (298), primarily due to incorrect data editing that was subsequently repaired.

Transect completion

2008

In 2008, more formalized procedures were implemented and were taught during training so that field crews would apply a standardized approach to sample in rugged areas but also adhere to safety guidelines. The proportion of transects that were altered due to terrain was used to estimate the proportion of the stratum in rugged terrain; a separate estimate was made using these transects and was applied to that proportional area of the stratum. A certain proportion of transects were completely unwalkable, and this proportion of the stratum area was also estimated. There were still alternative transects available, so that the same overall number of transects would be completed.

The number of transects completed, however, was still not very close to 100%. In California, this again resulted from lack of promised funding, but also from unexpected difficulties with the contracting mechanism that had been used since 2001. In this sense, the completion record in California is remarkably good and reflects the flexibility demonstrated by Kiva this year. In Nevada, Arizona, and Utah, the numbers are a bit misleading. In the regular long-term monitoring strata (the ones they had experienced in 2007), GBI completed 98% of the planned number of transects; quite good. However, as in 2007, the completion rate was much lower in strata the crews had no previous logistic experience with. In the new strata in Nye County, the primary difficulties were due to unmapped private property. In the new strata to the north of Mormon Mesa and Beaver Dam Slope, the issue was lack of known access routes, combined with a large proportion of the sampling area being in rugged terrain. In Coyote Springs and Mormon Mesa, it was determined that access routes do not exist to some areas where transects have never been completed (since 2001). In 2008, base camping was used to establish a drop off location where water and other supplies could be reached on foot by a handful of crews. This procedure adds to the cost of a transect, however, so not all areas were accessed this way, as reflected in Table 7.

When GBI did need to replace transects, they did not always select from the transects in the same stratum, which resulted in only 2 transects out of 11 being completed in the new Beaver Dam Slope 2 stratum. Also, a single day of confusion over transects that had already been assigned contributed to this team walking 5 transects 2 times (counted once in Table 7).

Table 7. Transect completion in 2008 and classification as standard, shortened, or unwalkable lengths. Stratum abbreviations as in Fig. 1

Stratum	Assigned	Completed (including replacements)	Percentage walked as 12k	Percentage walked as 6k	Percentage unwalkable	Assigned transects that were walkable but were not walked
AG	16	14	68.8	12.5	18.8	1
CK	6	10	50.0	0.0	50.0	0
BD	31	32	51.6	32.3	16.1	3
CS	167	159	45.5	27.3	27.3	4
GB	34	40	57.5	23.4	19.2	18
MM	73	74	32.4	41.2	26.5	2
BD2	11	2	53.4	28.8	17.8	2
MM2	53	51	52.8	28.3	18.9	10
PN	59	48	33.9	28.8	37.3	2
PS	74	75	70.3	12.2	17.6	0
PI	132	133	62.9	21.2	15.9	0
FE	10	9	100.0	0.0	0.0	2
IV	10	10	100.0	0.0	0.0	0
CM	10	7	90.0	0.0	10.0	0
FK	18	18	100.0	0.0	0.0	3
OR	10	9	70.0	20.0	10.0	0
SC	29	24	93.1	6.9	0.0	1
JT	7	10	57.1	28.6	14.3	3
PT	5	6	40.0	20.0	40.0	0
Total	755	731				
In long-term strata	558	555				

2009

Table 8 reports the number of assigned and completed transects in each stratum. The number completed in California was 1 more than the number planned (assigned). Although alternate transects are provided in case terrain precludes completion of some assigned transects, in 2009 large areas of Superior-Cronese and Fremont-Kramer were inaccessible following the crash of a military plane from Edwards Air Force Base. This area corresponded to 2 assigned transects in the Fremont-Kramer monitoring stratum and 11 in Superior-Cronese. Substitution of alternate transects for these assigned ones delayed completion of transects in these strata by only 1 day; however, substitution of so many alternate transects did affect the team's ability to complete transects in the order they were assigned. The supplemental transects on Edwards Air Force Base and on Ft. Irwin could not be completed in the original time period that had been approved by the facilities.

Kiva was also unable to access CMAGR (the Chocolate Mountain monitoring stratum) during the same time period as transects in Chuckwalla, Joshua Tree, and Pinto Mountains strata. Chocolate Mountain transects were instead completed in June, with additional monitoring of the telemetry site. Due to this time shift, the encounter rate on transects on Chocolate Mountain were corrected by a separate estimate of visibility (G_0).

Only 89% of transects assigned to GBI were completed, primarily due to early season loss of personnel. Four crew members left during the first 2 weeks of the field season for personal reasons or due to injury. Great Basin Institute had sufficient personnel to accommodate some attrition due to illness or other issues; however, since each crew was slated to walk 45 transects during the field season, loss of 2 crews for most of the field season was a contingency was not addressed by the budget. In May the USFWS reduced the number of expected transects by 71.

Great Basin Institute successfully implemented base-camping to sample areas that have not been accessible in past years. Base-camping into route-less areas allowed crews to be provisioned centrally with supplies, including water, while the crews hiked farther in to complete remote clusters of transects in areas that are more than 4 km from a motorized route. In all, 24 remote transects were completed using base-camping in CS, 8 in MM, and 4 in GB. Any field personnel provisioning these base camps for other crews are not themselves walking transects.

Table 8 indicates the number of assigned transects that could be completed as standard square 12 km transects (column 4), as well as the number that were completed by reflecting to avoid highways and fenced-off properties. These transects are all considered to represent flatter topography in the monitoring stratum. An additional number (column 5) were completed as 6 km squares, and represent more rugged terrain. Finally, some transects were considered unwalkable even when shortened to 6 km (column 6). The last 2 columns of Table 8 represent situations that were not anticipated. Crews were to shorten or abandon transects if the terrain presented too much of an obstacle, but reflecting around terrain was not a planned option. However, on some relatively rare occasions (column 7), crews had partially walked a transect before determining that it could not be completed following the correct protocol. In these situations, they would not have sufficient time to move to an alternate transect on the same day, so they instead reflected around terrain to collect data for the lower topography portion of the current transect. Column 8 reports transects that appear walkable based on remote imagery but were not completed. On investigation, all of these in the eastern part of the range were removed from the walk order during the field season to accommodate the reduced number of personnel (in BD, BD2, MM, MM2; see above). Those in California were not completed due to military restrictions such as those around the plane crash site or involving activities at particular installations (AG, FK, SC). Figures 9 through 16 show locations of transects and observations of live tortoises.

Table 8. Number and type of transects in each stratum in 2009. Stratum abbreviations as in Fig. 1

Stratum	Assigned transects	Assigned and alternate transects completed*	Assigned, completed 12k	Assigned, completed 6k	Assigned, judged unwalkable	Assigned, completed by avoiding terrain	Assigned, judged walkable, but not walked*
AG	33	33	24	3	3		3
BD	69	66	26	19	10		8
BD2	20	19	7	6	6		1
CK	12	12	6	3			1
CM	10	10	8		2	2	0
CS	174	153	73	39	24	14	18
FE	10	10	8				0
FK	30	30	22		1		3
GB	77	76	25	18	9	1	1
IV	10	10	6				0
JT	25	25	11	6	4		2
MM	165	137	45	55	27		29
MM2	80	61	26	12	16		25
OR	20	20	6	7	2		2
PI	80	80	33	21	6		0
PT	17	17	5	3	4		3
SC	69	70	37	5	1	1	13
Total	901	829	368	197	115	18	109
In long-term strata	801	749					

*Assigned transects that were not walked were generally replaced by alternates.

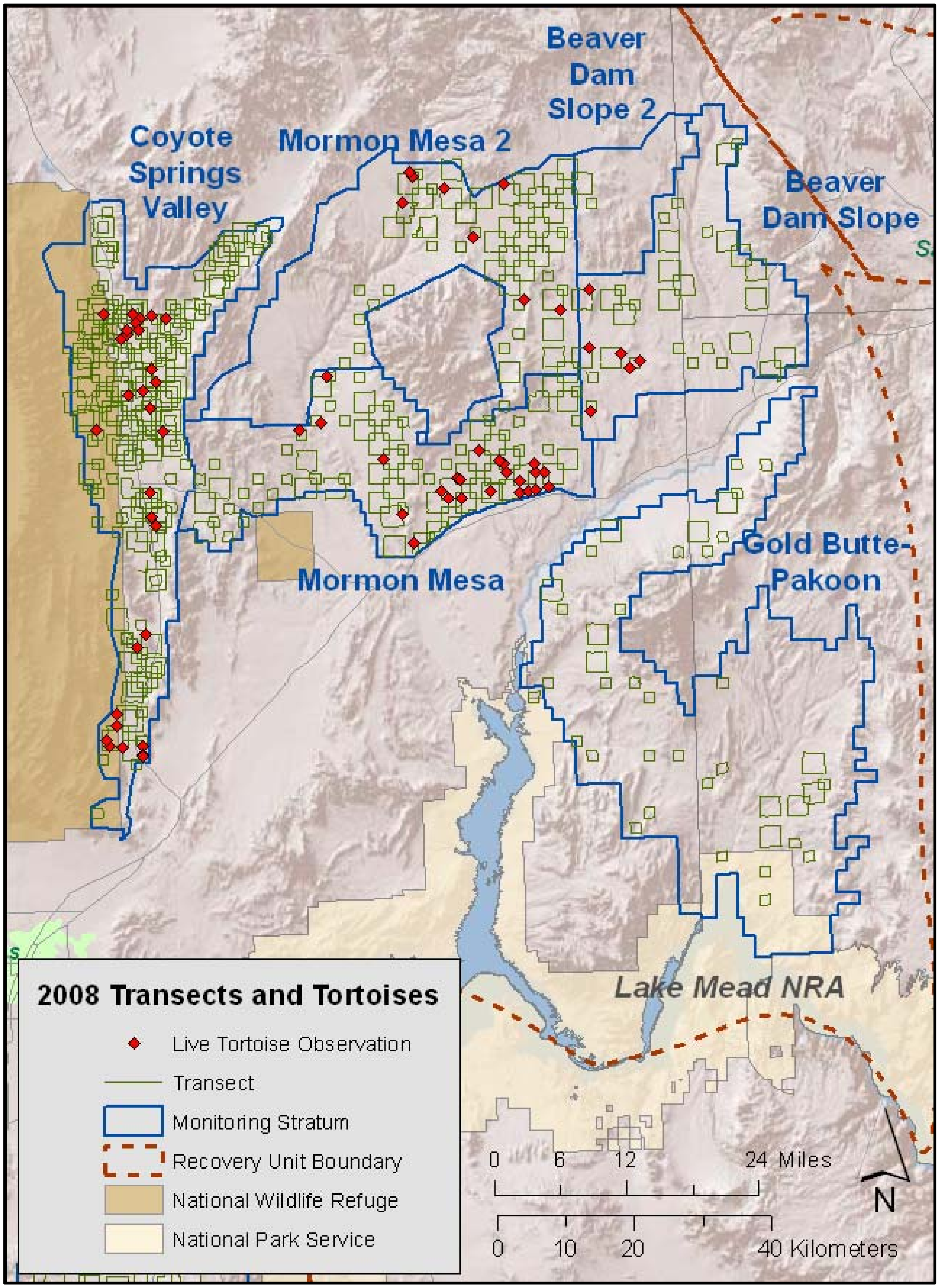


Figure 9. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs, Mormon Mesa, Mormon Mesa 2, Beaver Dam Slope, Beaver Dam Slope 2, and Gold Butte-Pakoon monitoring strata.

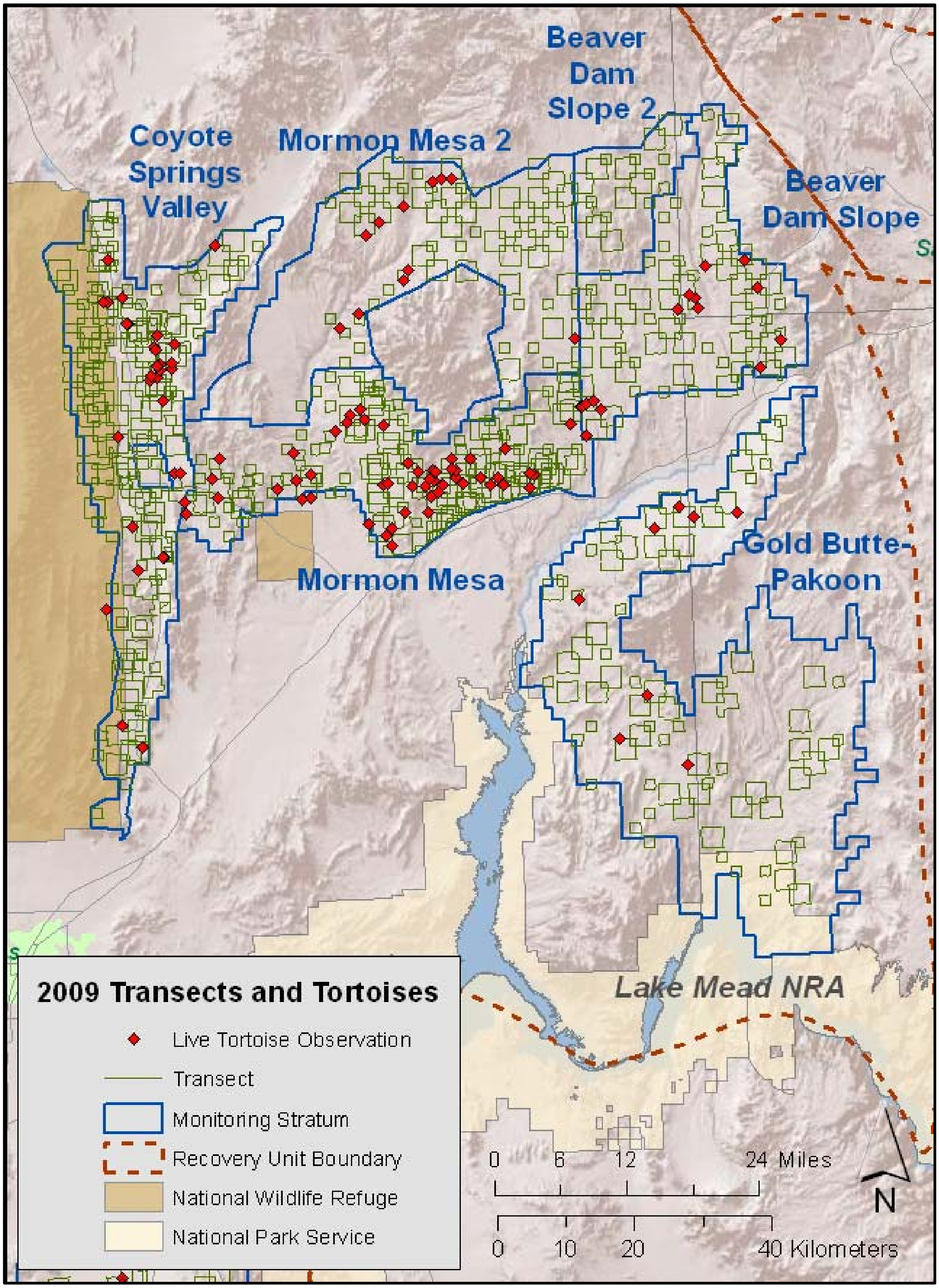


Figure 10. Distribution of distance sampling transects and live tortoise observations in the Coyote Springs, Mormon Mesa, Mormon Mesa 2, Beaver Dam Slope, Beaver Dam Slope 2, and Gold Butte-Pakoon monitoring strata.

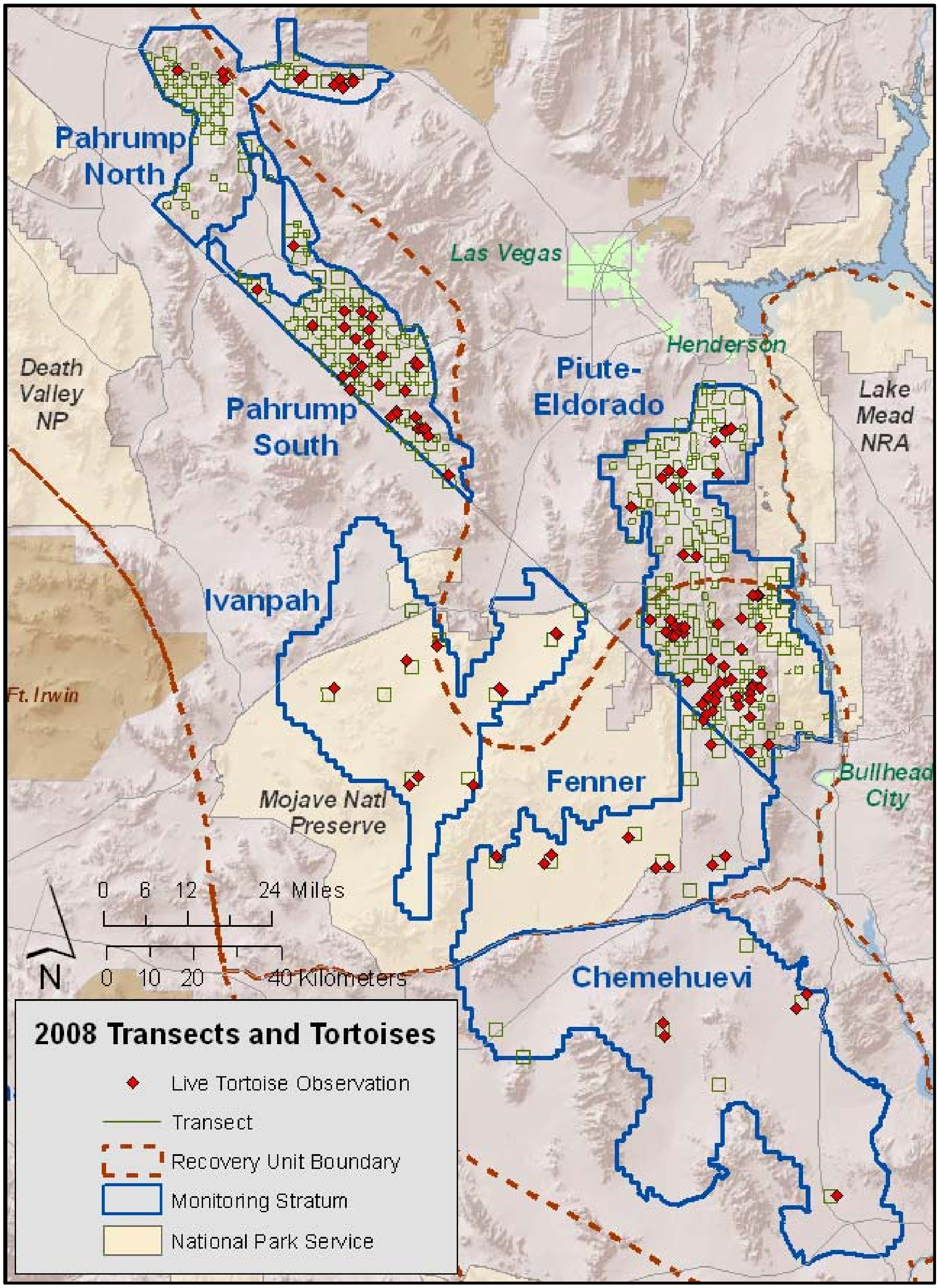


Figure 11. Distribution of distance sampling transects and live tortoise observations in 2008 in the Piute-Eldorado, Ivanpah, Fenner, and Chemehuevi long-term monitoring strata and in Pahrump North and Pahrump South monitoring strata.

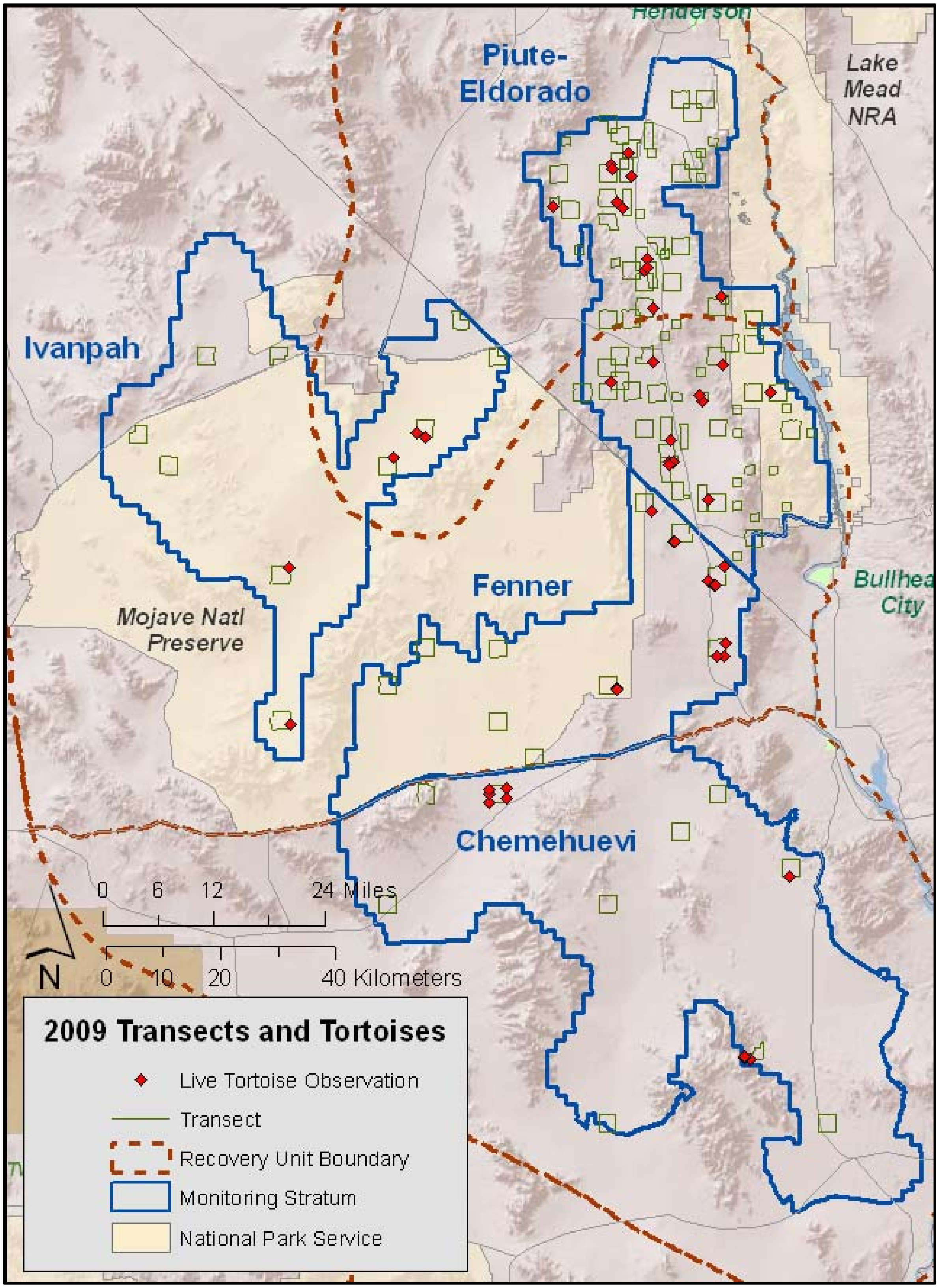


Figure 12. Distribution of distance sampling transects and live tortoise observations in the Piute-Eldorado, Ivanpah, Fenner, and Chemehuevi monitoring strata.

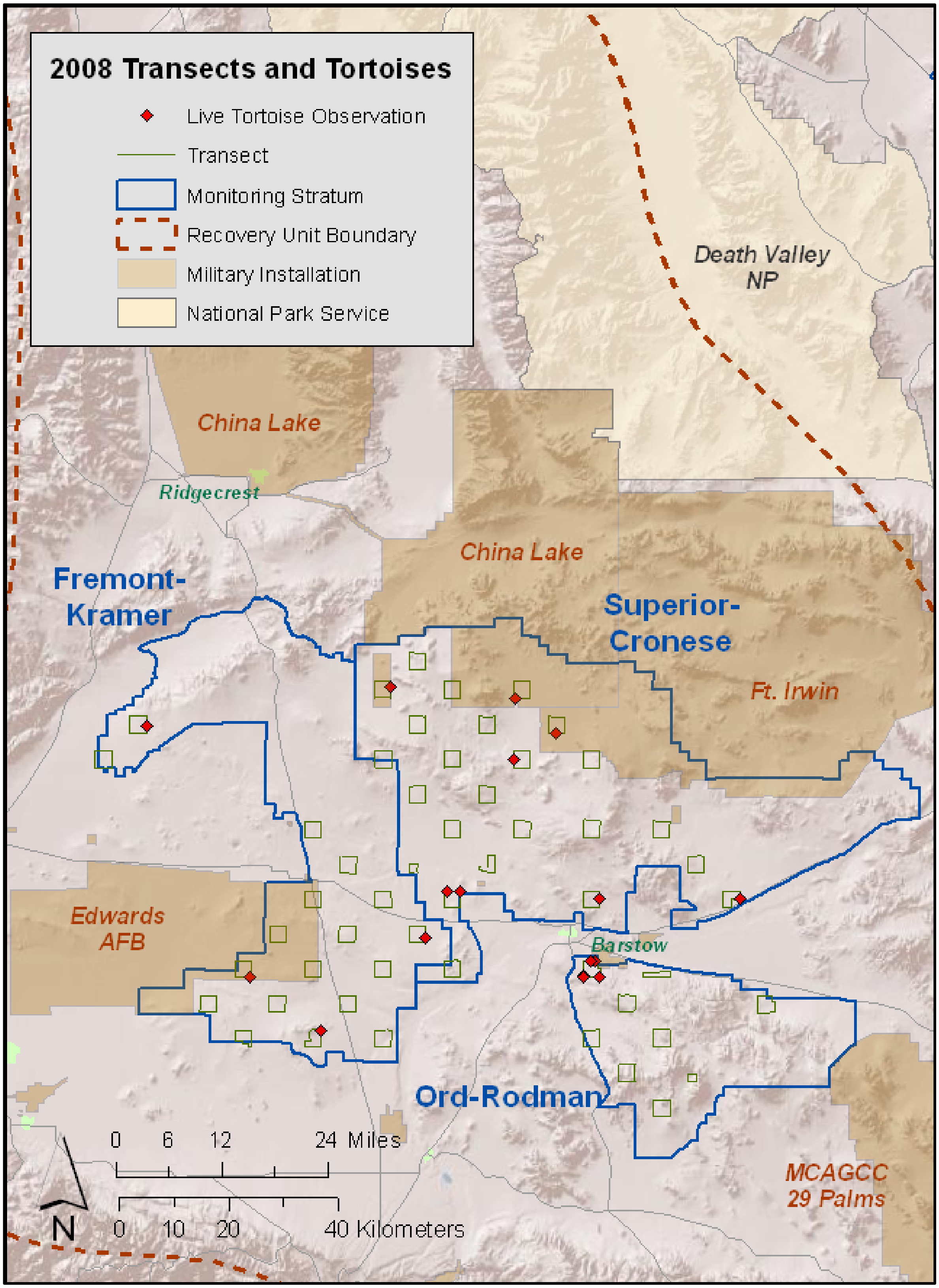


Figure 13. Distribution of distance sampling transects and live tortoise observations in 2008 in the Fremont-Kramer, Ord-Rodman, and Superior-Cronese monitoring strata.

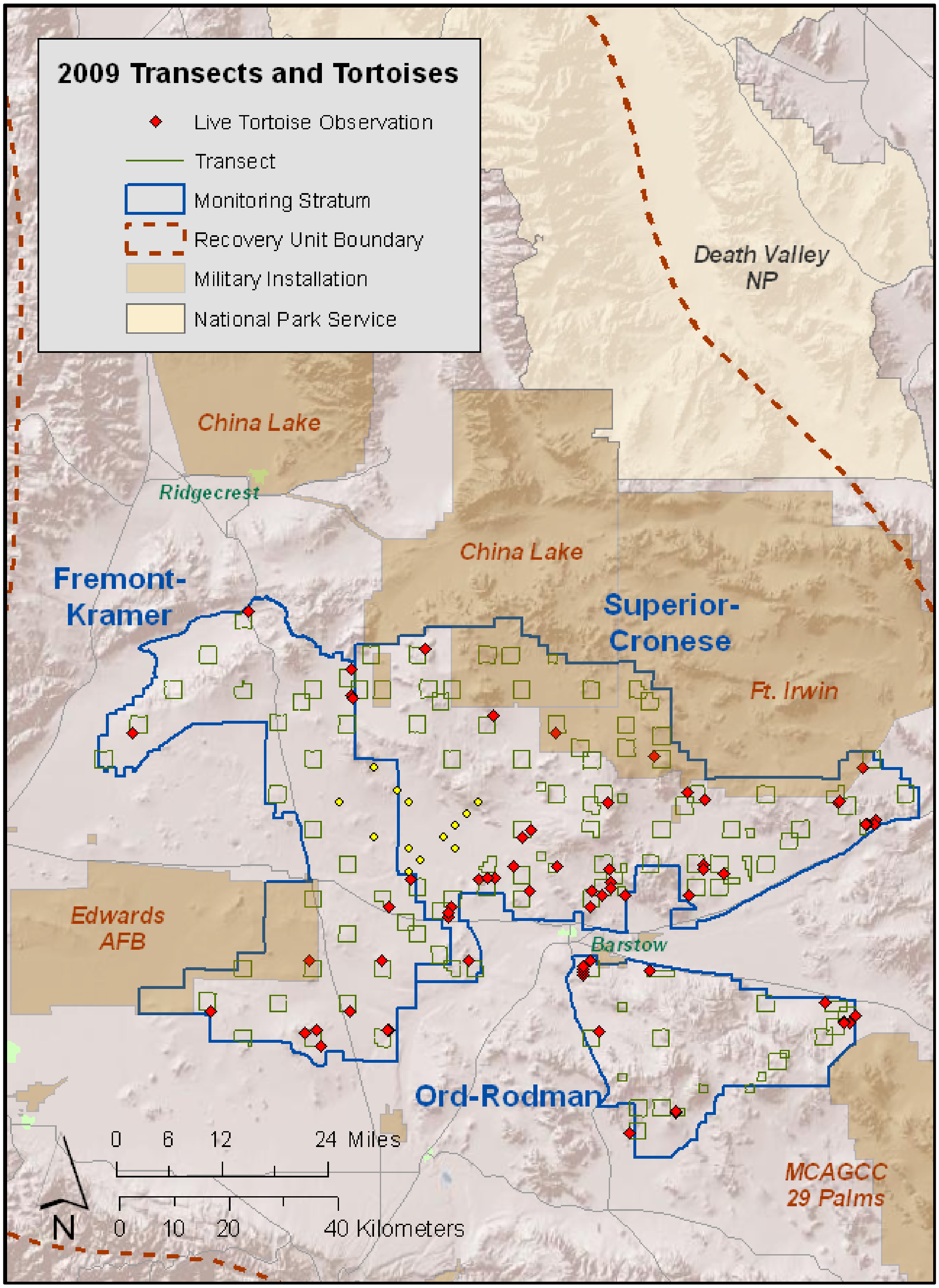


Figure 14. Distribution of distance sampling transects and live tortoise observations in 2009 in the Fremont-Kramer, Superior-Cronese, and Ord-Rodman monitoring strata. Yellow diamonds mark the SW corner of transects that were planned in FK and SC, but were instead replaced after road closures following a plane crash in this area.

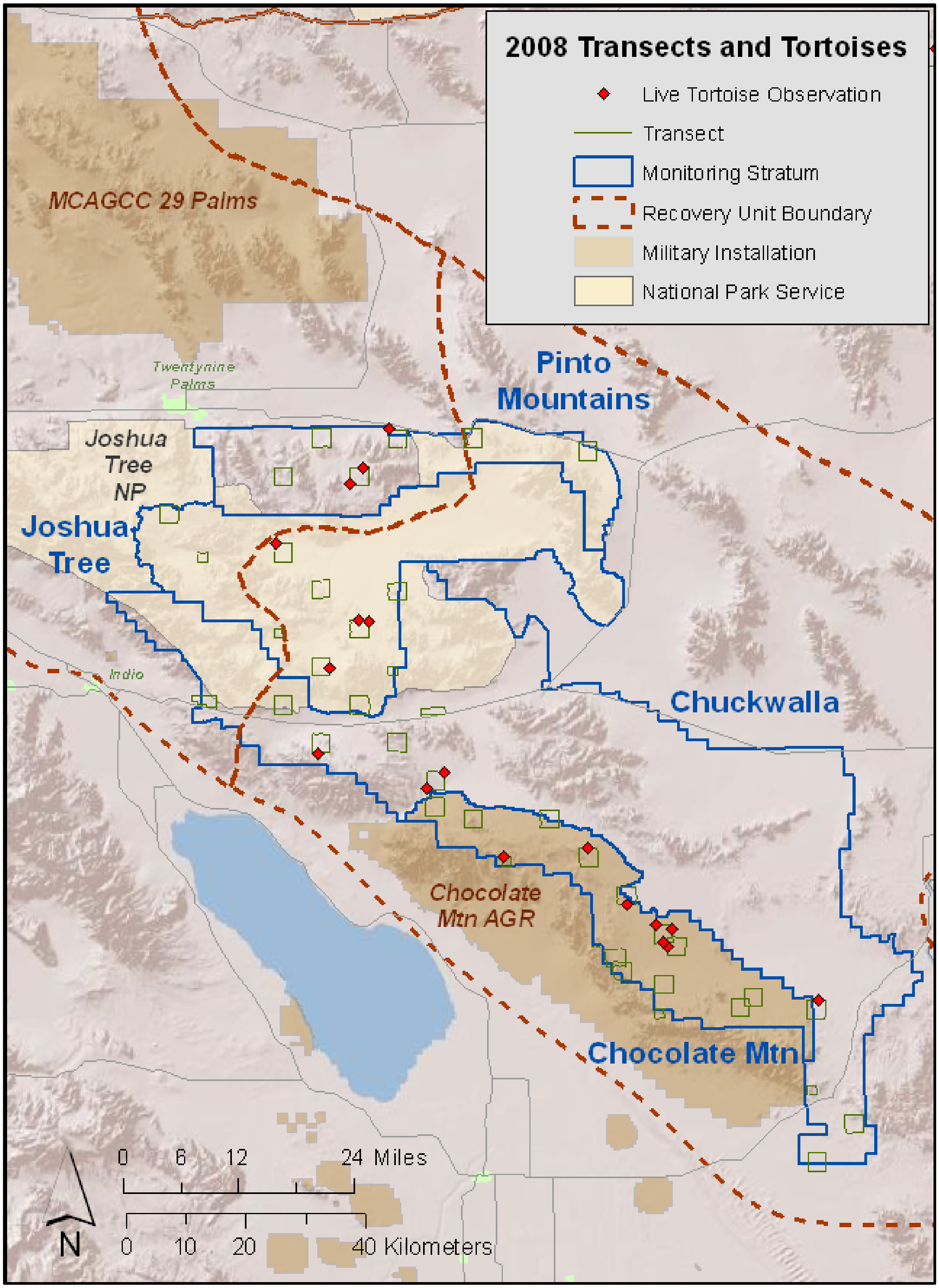


Figure 15. Distribution of distance sampling transects and live tortoise observations in 2008 in the Pinto Mountains, Joshua Tree, Chuckwalla, and Chocolate Mountain monitoring strata.

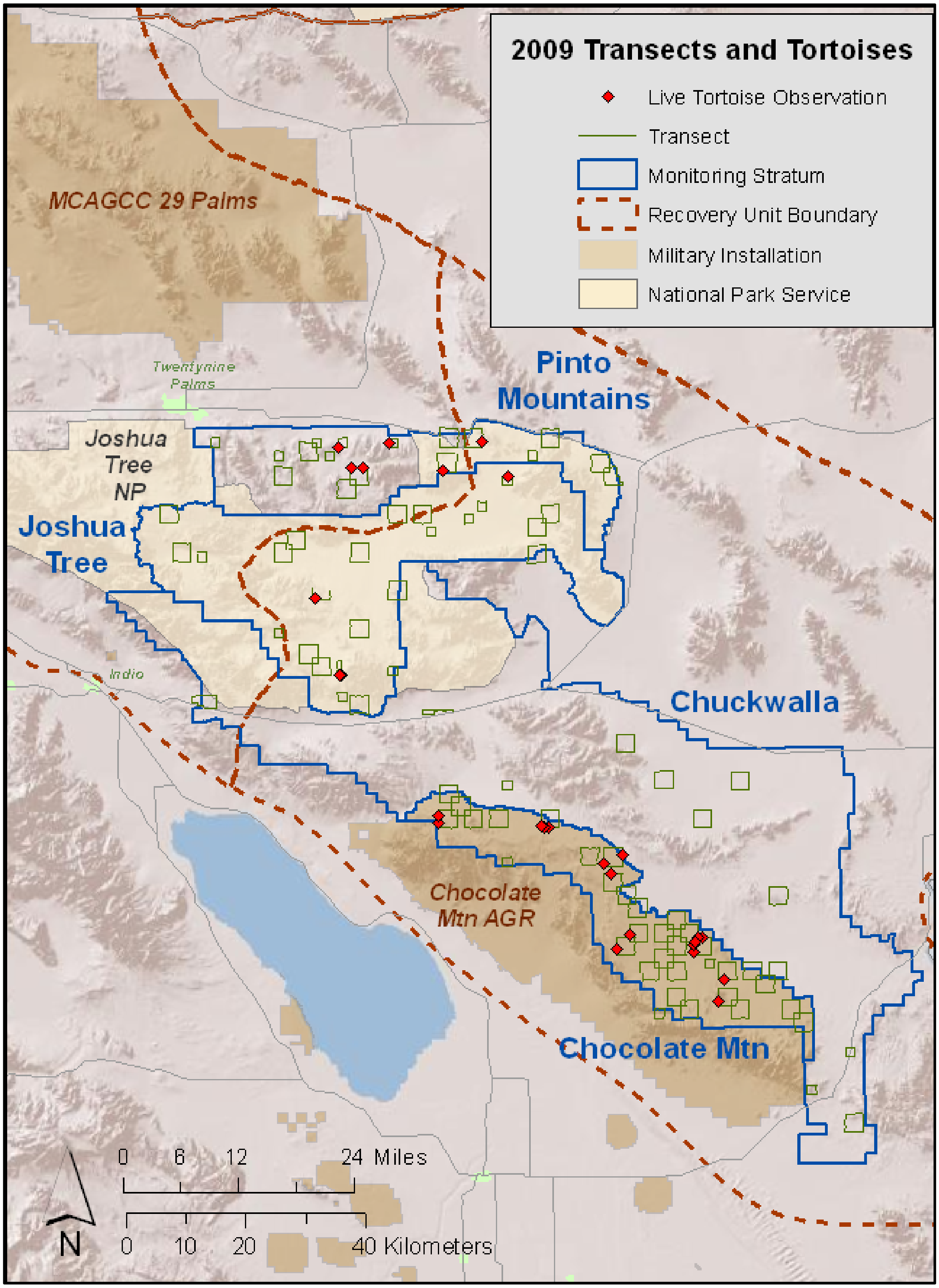


Figure 16. Distribution of distance sampling transects and live tortoise observations in 2009 in the Pinto Mountains, Joshua Tree, Chuckwalla, and Chocolate Mountain monitoring strata.

Tortoise encounter rates and detection functions

Figures 17 to 20 are histograms of the observed number of tortoises seen at increasing distance from the transect centerline, with one curve for each field team each year. These observations were used to model detection curves, overlaid in the same figures. Based on detection function behavior, it is typical to discard the most distant observations in the tails of the histograms in order to build a more robust model (Buckland et al. 2001). Each figure indicates the truncation distance that was applied. Observations that are not used to estimate detection functions were also not used to estimate the encounter rate (tortoises detected per kilometer walked). In distance sampling applications for many other species, encounter rate can be estimated with relatively high precision, but tortoise encounter rates are low enough that this becomes a factor in considering how to truncate observations to develop detection functions. Truncation was therefore conservative in order to maximize the number of observations per stratum.

Detection curves were estimated separately for each of the monitoring field teams (GBI and Kiva) each year. In 2008, crews for Kiva walked half as many days as those for GBI, and they sampled different halves of the range. I considered building a single detection curve to optimize use of the relatively few live tortoise observations, but also tested separate models for Kiva and GBI in order to benefit from pooling robustness. In fact, the curves for the two teams were considerably different, so separate detection functions were built. For Kiva, a uniform function with a first-order cosine adjustment term was selected (Fig. 17). The only competing model with a lower AIC was a negative exponential model (ΔAIC = 0.82).

For GBI in 2008, a uniform model with third-order cosine adjustment was selected (Fig 18). The hazard rate function had a lower AIC, but only by 1.67 points, so the best-fitting uniform model was selected on the basis of much better fit within 6 m of the centerline.

The area below these curves in Figs. 17 (Kiva) and 18 (GBI) is the proportion of tortoises that were detected, P_a, estimated as far as the truncation distance (the farthest distance on the x-axis in each figure). Based on these curves, in 2008 GBI detected 40.3% of the visible tortoises within 18m of the centerline (CV=0.097). Kiva detected 62.1% (CV=0.111) within 14 m.

In 2009, for Kiva (Fig. 19), a half-normal function with second-order cosine adjustment had the lowest AIC value (the spread between the best 3 models was 1.58). The precision of the best hazard, uniform, and half-normal models was similar, and there was no other reason to use a model with a larger AIC. On the basis of the half-normal model, Kiva crews detected 35.8% (CV=0.097) of tortoises within 14 m of the transect centerline. For GBI, a hazard rate function was selected (Fig. 20) because the best-fitting half-normal and uniform models had ΔAIC s of more than 2. The detection rate for GBI crews within 15 m of the transect centerline was 25.9% (CV=0.215).

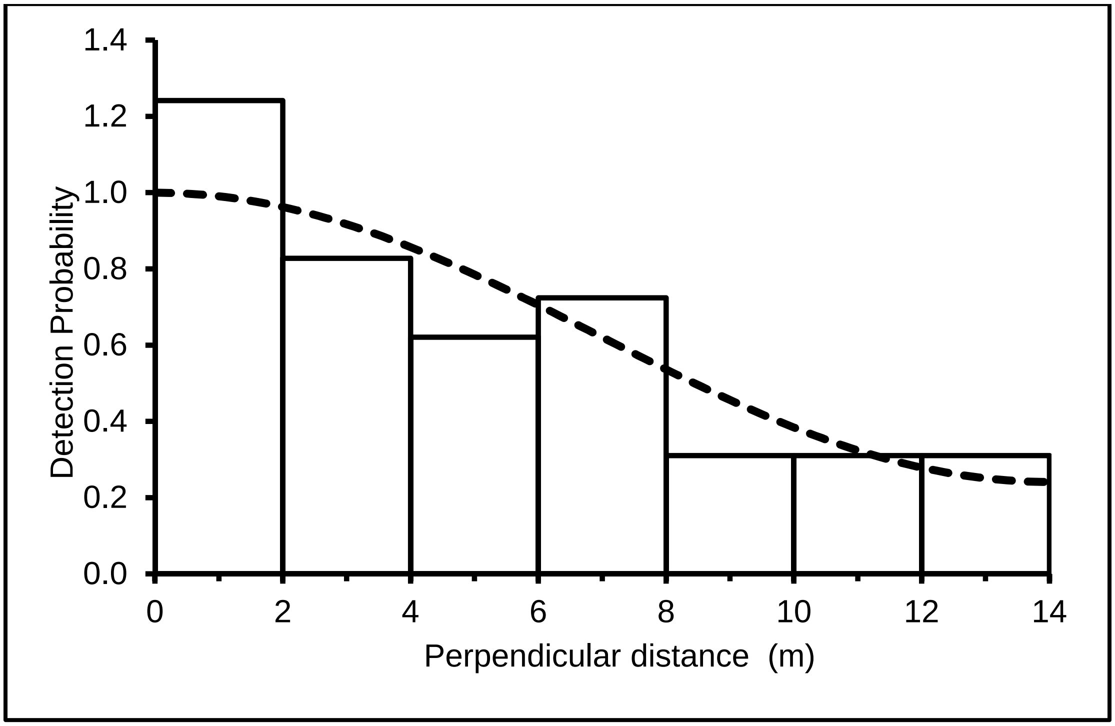


Figure 17. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in 2008. The curve is based on the 42 tortoises seen within 14 m of the centerline.

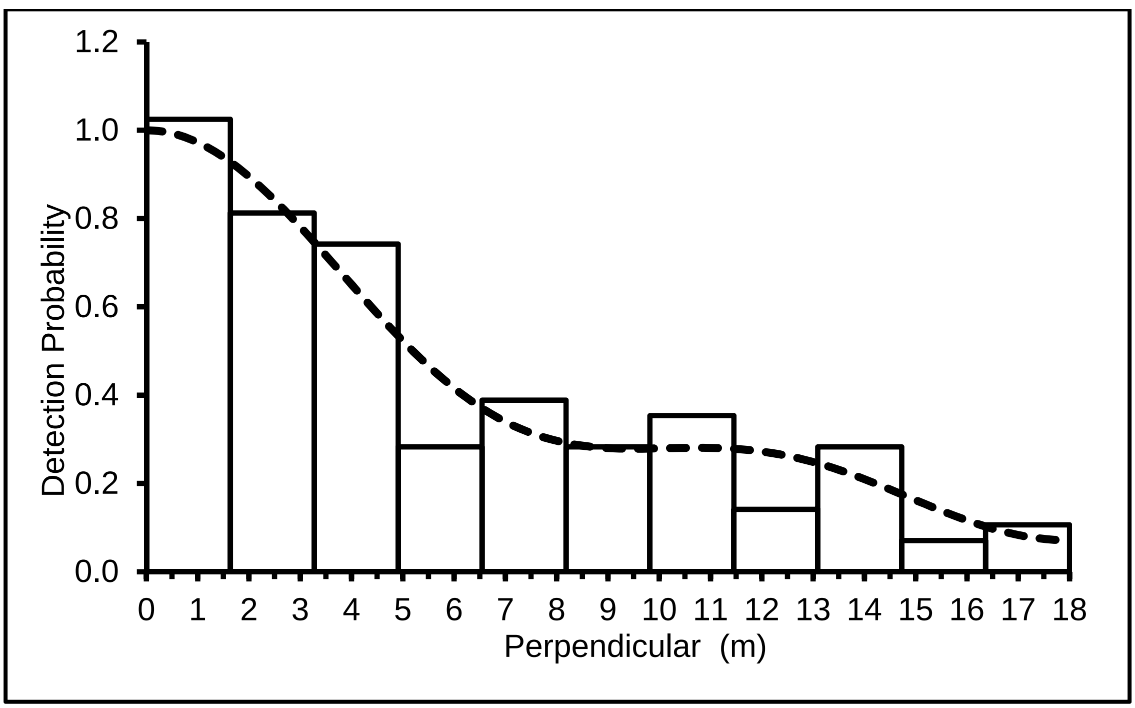


Figure 18. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI in 2008. The curve is based on the 127 tortoise seen within 18 m of the centerline.

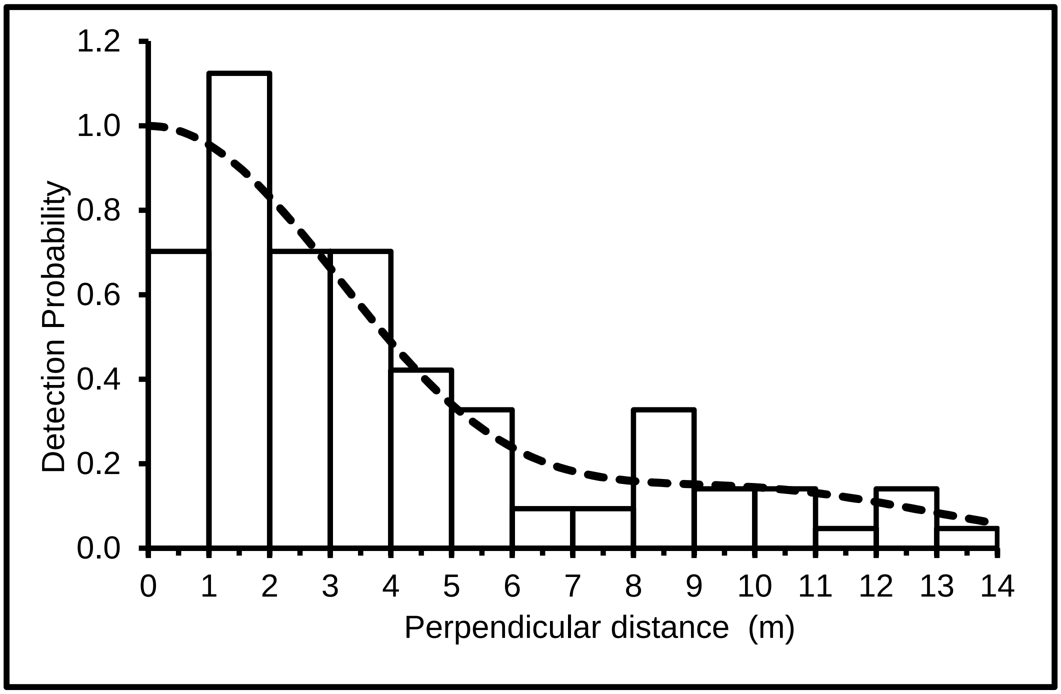


Figure 19. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by Kiva in 2009. The curve is based on the 107 tortoises seen within 14 m of the centerline.

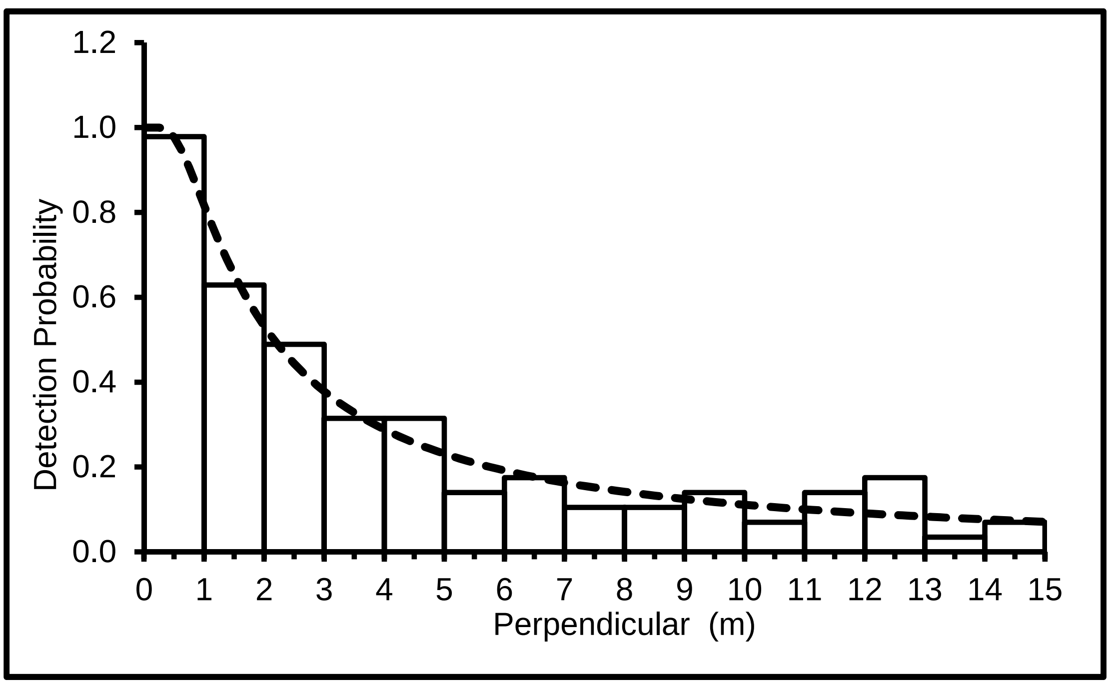


Figure 20. Observed detections (histogram) and the resulting detection function (smooth curve) for live tortoises with MCL ≥ 180mm found by GBI in 2009. The curve is based on the 111 tortoises seen within 15 m of the centerline.

Proportion of tortoises that are available for detection, G_0

2008

In general, telemetry sites and associated transects were completed sequentially, from south to north. This pattern corresponds to the expected timing of tortoise activity; activity should peak first in the south, later in the north. Dates, total days monitored, and G_0 estimates are given in Table 9.

Table 9. Availability of tortoises (G_0) during the period in 2008 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Chemehuevi, Ivanpah, Piute	Piute-Eldorado, Chemehuevi, Ivanpah, Fenner	31 Mar – 11 April	12	0.75 (0.13)
MCAGCC, Chuckwalla	Joshua Tree, Pinto Mountains, Chuckwalla, Chocolate Mountain	8 – 12 April	5	0.64 (0.15)
Superior-Cronese, Ord-Rodman	Superior-Cronese, Ord-Rodman, Fremont-Kramer	13 – 24 May	12	0.75 (0.16)
Coyote Springs	Beaver Dam Slope, Beaver Dam Slope 2, Coyote Springs, Mormon Mesa2, Mormon Mesa, Gold Butte	12 April – 16 May	35	0.83 (0.15)
Coyote Springs late	Pahrump North, Pahrump South	17 – 30 May	14	0.67 (0.24)

2009

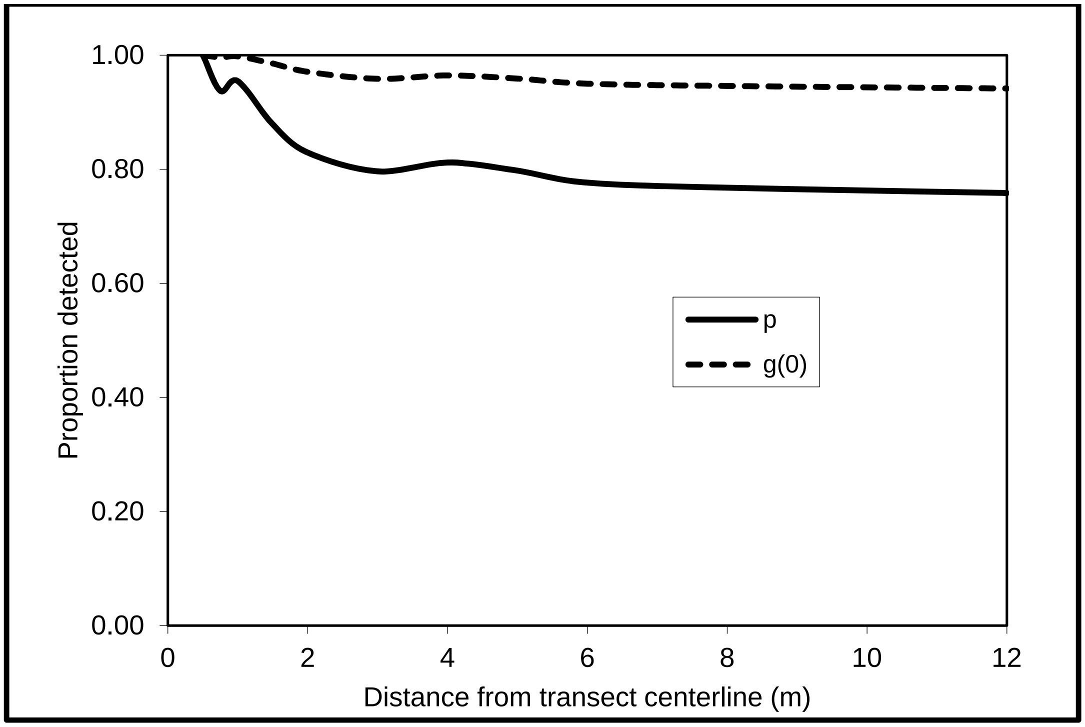
In general, telemetry sites and associated transects were completed sequentially, from south to north. To match the scheduling of military operations on CMAGR, transects in the Chocolate Mountain stratum were completed a month later than those in the neighboring Chuckwalla stratum, and after strata to the north. During the first 5 days of the field season, visibility information describing the same focal tortoises at the Piute telemetry site was not consistent between observers, so this site was not used to calculate G_0. No discrepancy was noted after that week. Dates, total days monitored, and G_0 estimates are given in Table 10.

Table 10. Availability of tortoises (G_0) during the period in 2009 when transects were walked in each group of neighboring strata.

G_0 sites	Strata	Dates	Days	G_0 (Std Error)
Chemehuevi, Ivanpah	Piute-Eldorado, Chemehuevi, Ivanpah, Fenner	1 – 5 April	5	0.82 (0.13)
Joshua Tree, Chuckwalla	Joshua Tree, Pinto Mtns, Chuckwalla	27 April – 6 May	10	0.73 (0.17)
Superior-Cronese, Ord-Rodman	Superior-Cronese, Ord-Rodman, Fremont-Kramer	6 – 25 April	20	0.93 (0.10)
Chuckwalla	Chocolate Mtn	2 – 6 June	5	0.58 (0.11)
Halfway Wash	Beaver Dam Slope, Beaver Dam Slope 2, Mormon Mesa2, Mormon Mesa, Gold Butte	23 April – 30 May	38	0.64 (0.17)
Coyote Springs	Coyote Springs	8 – 23 April	16	0.88 (0.12)

Proportion of available tortoises detected on the transect centerline, *g(0)*

Because they are cryptic, even tortoises that are visible (not covered by dense vegetation or out of sight in a burrow) may not be detected. In 2008, for 23 detections of tortoises within 1 m of the transect centerline, 22 were found by the observer in the lead position and 1 by the follower. Although this is technically the ratio of interest, with only one detection by the follower, it is an unreliable estimate, which is why the proportion detected by the leader (and the resulting *g(0)* estimate) were examined graphically, based on smaller and smaller intervals from the transect line. Using a wider interval, say 5 m from the transect line, the overall number of detection is greater (95, with 16 by the follower), so the ratio is easier to estimate but also less relevant to figuring out the detection probability right at the line. In 2009, for 43 detections of tortoises within 1m of the transect centerline, 38 were found by the observer in the lead position and 5 by the follower, so that the probability of detection by single observer was $p = 0.868$, and the proportion detected using the dual observer method was *g(0)* = 0.989 (SE = 0.06). However, Fig. 21 shows that *g(0)* was converging on 1.0 in both 2008 and 2009, indicating the assumption of perfect detection on the centerline was reasonable; consequently, no adjustment was made to the final density estimate. The curves since 2004 have all supported the premise that complete detection on the transect line was achieved for previous years in which the dual-observer method was used (USFWS 2009).



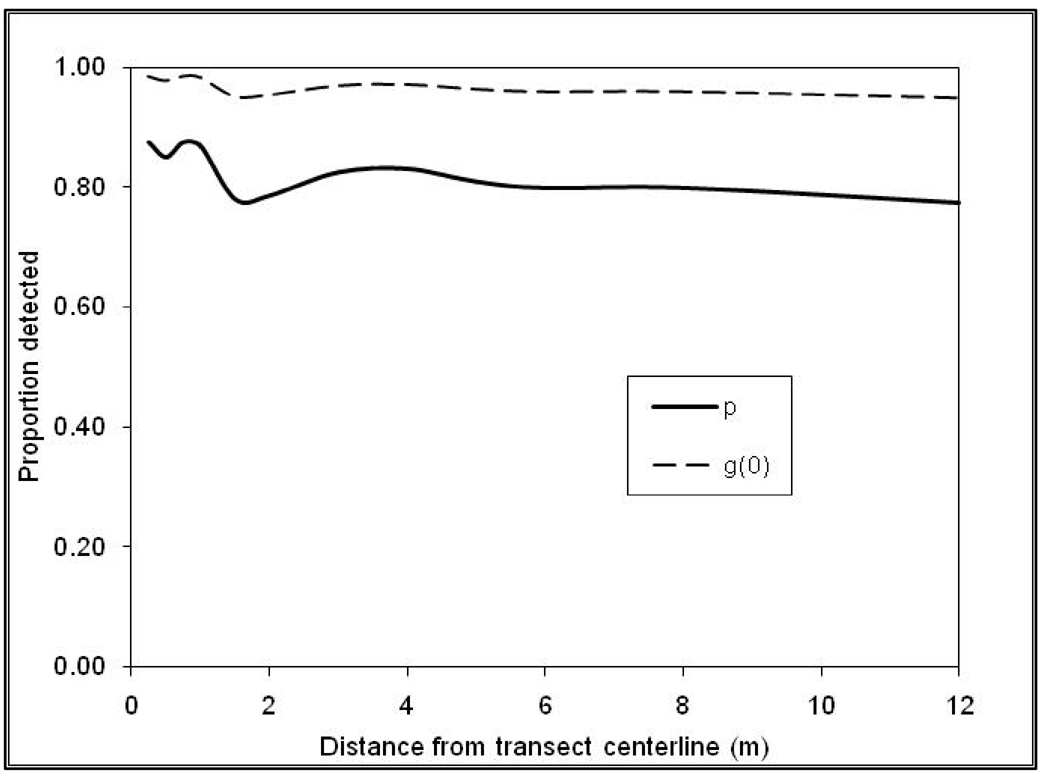


Figure 21. Detection pattern for the leader (*p*) and by the team (*g(0)*) based on all observations out to a given distance (*x*) from the centerline in 2008 (above) and 2009 (below).
In both years, the leader generally made 75-80% of all detections, increasing within 1.5 m of the line. Note convergence of *g(0)* on 1.0 as *x* goes to 0.

Estimates of tortoise density

Density estimates were generated separately for each monitoring stratum (Tables 11 and 12). Stratum estimates were weighted by stratum area to arrive at average density in the monitored area of each recovery unit. Although encounter rates were estimated separately for each stratum and have independent variances, the detection function and G_0 were estimated jointly (pooling data from multiple strata), so these variances are not independent. Figure 4 illustrated how estimates were pooled each year.

Recovery-unit-level density estimates are provided in Tables 13 and 14. The Northern and Eastern Colorado recovery units were under-sampled in both years, reflected in the low precision (high CV) reported for the Northern Colorado. Low precision means that high between-year fluctuations in estimates are to be expected. Only 12 transects were placed on BLM lands in the Eastern Colorado (Chuckwalla monitoring stratum) in 2009. The under-sampling in this recovery unit resulted in no density estimate for Chuckwalla or the recovery unit this year.

When the annual estimates are imprecise, it should not be expected that there will be a close match from one year to the next. Over a period of many years, however, any underlying trend in the number of tortoises should be obvious through this “background noise.”

Table 11. Recovery unit and stratum-level encounters and densities in 2008 for tortoises with MCL ≥ 180mm

Recovery Unit	Stratum		Area (km^2)	Number of Transects	Total transect length (km)	Sampling Dates Begin	Sampling Dates End	Field Observers	n (tortoises observed)	CV(n)	Density ($/km^2$)	CV(Density)
Northeastern Mojave			**4917**	**305**	**2886**	**11-Apr**	**18-May**		**44**			
	Beaver Dam Slope	BD	828	32	295	12-Apr	14-May	GBI	4	48.0	1.1	52.4
	Coyote Springs Valley	CS	1144	159	1592	11-Apr	18-May	GBI	24	22.0	1.2	30.8
	Gold Butte-Pakoon	GB	1977	40	308	13-Apr	16-May	GBI	0			
	Mormon Mesa	MM	968	74	691	12-Apr	15-May	GBI	16	31.8	1.9	38.0
	Beaver Dam Slope 2*	BD2	260	2	18	3-May	3-May	GBI	0			
	Mormon Mesa 2*	MM2	1154	51	499	13-Apr	16-May	GBI	6	38.9	1.0	44.1
Northeastern Mojave (Pahrump)			**2178**	**123**	**1321**	**17-May**	**30-May**		**36**		**2.4**	**42.5**
	Pahrump North*	PN	1062	48	474	17-May	30-May	GBI	9	43.8	1.7	55.7
	Pahrump South*	PS	1117	75	847	19-May	29-May	GBI	27	21.2	2.9	43.9
Eastern Mojave			**6763**	**153**	**1590**	**31-Mar**	**11-Apr**		**61**		**3.9**	**26.0**
	Fenner	FE	1862	9	108	2-Apr	5-Apr	Kiva	7	28.6	5.0	34.9
	Ivanpah	IV	2567	10	120	1-Apr	4-Apr	Kiva	6	44.4	3.8	48.7
	Piute-Eldorado	PI	2334	134	1362	31-Mar	11-Apr	GBI	48	20.4	3.0	28.8
Northern Colorado			**4038**	**7**	**84**	**3-Apr**	**4-Apr**		**4**		**3.6**	**55.7**
	Chemehuevi	CM	4038	7	84	3-Apr	4-Apr	Kiva	4	52.0	3.6	55.7
Western Mojave			**9351**	**67**	**772**	**7-May**	**24-May**		**15**		**1.4**	**41.3**
	Fremont-Kramer	FK	2462	18	216	14-May	23-May	Kiva	1	100.0	0.4	103.0
	Joshua Tree	JT	1567	10	102	7-May	9-May	Kiva	2	64.3	1.8	69.0
	Ord-Rodman	OR	1124	9	102	13-May	24-May	Kiva	5	99.4	3.8	102.4
	Pinto Mountains	PT	751	6	72	7-May	10-May	Kiva	2	100.0	2.5	103.1
	Superior-Cronese	SC	3447	24	281	13-May	21-May	Kiva	5	49.7	1.4	55.5
Eastern Colorado			**4263**	**25**	**270**	**8-May**	**13-May**		**10**		**3.2**	**50.3**
	Chocolate Mountain	AG	755	15	158	11-May	13-May	Kiva	6	40.8	3.4	47.9
	Chuckwalla	CK	3509	10	112	8-May	10-May	Kiva	4	54.2	3.2	59.8

* These strata are not part of long-term monitoring and were not included in recovery-unit summary rows.

Table 12. Recovery unit and stratum-level encounters and densities in 2009 for tortoises with MCL ≥ 180mm

Recovery Unit	Sampling Area		Area (km^2)	Number of Transects	Total Transect Length (km)	Sampling Dates: Begin	Sampling Dates: End	Field Observers	n (tortoises observed)	CV(n)	Density ($/km^2$)	CV(Density)
Northeastern Mojave			**4889**	**430**	**4154**	**8-Apr**	**30-May**		**85**		**3.4**	**34.1**
	Beaver Dam Slope	BD	828	66	631	29-Apr	29-May	GBI	10	35.8	3.2	49.2
	Coyote Springs Valley	CS	1117	151	1504	8-Apr	25-Apr	GBI	20	26.2	2.0	36.4
	Gold Butte-Pakoon	GB	1977	76	733	27-Apr	30-May	GBI	8	37.6	2.2	50.5
	Mormon Mesa	MM	968	137	1286	22-Apr	29-May	GBI	47	16.9	7.3	37.7
	Beaver Dam Slope 2*	BD2	260	19	174	28-Apr	28-May	GBI	0			
	Mormon Mesa 2*	MM2	1157	61	589	23-Apr	30-May	GBI	7	36.2	2.4	49.4
Eastern Mojave			**6763**	**100**	**1047**	**1-Apr**	**8-Apr**		**31**		**5.1**	**29.1**
	Fenner	FE	1862	10	121	1-Apr	4-Apr	Kiva	8	44.9	8.1	48.6
	Ivanpah	IV	2567	10	120	1-Apr	5-Apr	Kiva	4	40.9	4.0	44.9
	Piute-Eldorado	PI	2334	80	806	1-Apr	8-Apr	GBI	19	22.6	3.7	34.9
Northern Colorado			**4038**	**10**	**119**	**1-Apr**	**4-Apr**		**9**		**9.2**	**63.3**
	Chemehuevi	CM	4038	10	119	1-Apr	4-Apr	Kiva	9	60.5	9.2	63.3
Western Mojave			**9351**	**161**	**1742**	**6-Apr**	**6-May**		**70**		**4.3**	**19.3**
	Fremont-Kramer	FK	2462	30	361	6-Apr	28-Apr	Kiva	11	30.6	3.3	33.7
	Joshua Tree	JT	1567	25	240	26-Apr	6-May	Kiva	4	61.9	2.3	67.0
	Ord-Rodman	OR	1124	20	197	5-Apr	26-Apr	Kiva	13	33.8	7.1	36.7
	Pinto Mountains	PT	751	17	162	26-Apr	5-May	Kiva	6	41.7	5.0	49.0
	Superior-Cronese	SC	3447	69	781	5-Apr	26-Apr	Kiva	36	19.1	4.9	23.8
Eastern Colorado			**4263**	**45**	**504**	**25-Apr**	**6-Jun**		**16**			
	Chocolate Mountain	AG	755	33	378	2-Jun	6-Jun	Kiva	16	29.6	7.3	36.4
	Chuckwalla	CK	3509	12	126	25-Apr	6-May	Kiva	0			

* These strata are not part of long-term monitoring and were not included in recovery-unit summary rows.

Table 13. Estimated density of desert tortoises in monitored areas of Pahrump Valley and in tortoise conservation areas of each recovery unit in the Mojave Desert in 2008.

Recovery Unit	Monitored area (km^2)	Kilometers walked	Tortoises detected	Density ($/km^2$)	Lower limit 95% CI (Density)	Upper limit 95% CI (Density)	%CV (Density)
Eastern Colorado	4263	270	10	3.2	1.27	8.20	50.3
Eastern Mojave	6763	1590	61	3.9	2.34	6.39	26.0
Northeastern Mojave[a]	4917	2886	44	-	-	-	-
Northern Colorado	4038	84	4	3.6	1.31	10.13	55.8
Western Mojave	9351	772	15	1.4	0.66	3.13	41.3
Pahrump Valley	2178	1321	36	2.4	1.09	5.37	42.5

[a] No tortoises were detected on the 40 transects that were walked in the Gold Butte stratum. This prevents estimation of the number of tortoises in the larger Northeastern Recovery Unit as well.

Table 14. Estimated density of desert tortoises in monitored areas of each recovery unit in the Mojave Desert in 2009.

Recovery Unit	Monitored area (km^2)	Kilometers walked	Tortoises detected	Density ($/km^2$)	Lower limit 95% CI (Density)	Upper limit 95% CI (Density)	%CV (Density)
Eastern Colorado[a]	4263	504	16	-	-		-
Eastern Mojave	6763	1047	31	5.1	2.91	8.96	29.3
Northeastern Mojave	4889	4154	85	3.4	1.75	6.42	34.1
Northern Colorado	4038	119	9	9.2	2.96	28.76	63.3
Western Mojave	9351	1742	70	4.3	2.95	6.23	19.3
Upper Virgin River	114	310	84	13.5	10.0	18.1	15.0

[a] No tortoises were detected on the 12 transects that were walked in the Chuckwalla stratum. This prevents estimation of the number of tortoises in the larger Eastern Colorado Recovery Unit as well.
[b] Data for Upper Virgin River from McLuckie et al. (2012)

Area of each stratum sampled and the number of tortoises in that area

Proportion of each stratum walked

Since 2008, transects have been selected from the same set of potential transects, and these have been classified as transects that should be walked for a full 12 km, shortened to 6 km, or should not be attempted at all. This classification process has been completed based on data through 2010. Each year, new transects were tested, and previously walked transects were reevaluated by field crews. The proportion of each stratum represented by distance sampling is calculated based on the proportion of transects shortened and/or replaced (Table 15). After 2010, other options for shortening transects were implemented, so a slightly different formula was used to estimate the proportion walkable area in each stratum (USFWS 2012). Using this larger set of information (761 additional transects), Table 16 (2008) and Table 17 (2009) report the area of each stratum, the proportion covered by our density estimates, and the associated estimate of tortoise abundance.

Table 15. Proportion of each stratum that can be sampled based on all transects classified from 2008 through 2010. Stratum abbreviations as in Fig. 1

Stratum	Transects classified	Percentage of transects expected to be …			Proportion of stratum that can be sampled
		12 km	6 km	Replaced	
AG	66	86.4	9.1	4.5	0.955
BD	95	61.1	29.5	9.5	0.905
BD2	27	48.1	29.6	22.2	0.778
CK	112	60.7	13.4	25.9	0.741
CM	51	78.4	7.8	13.7	0.863
CS	127	59.8	29.1	11	0.890
FE	37	89.2	5.4	5.4	0.946
FK	53	94.3	5.7	0	1.000
GB	203	45.8	33	21.2	0.788
IV	57	78.9	10.5	10.5	0.895
JT	60	51.7	25	23.3	0.767
MM	105	52.4	39	8.6	0.914
MM2	112	53.6	28.6	17.9	0.821
OR	51	54.9	21.6	23.5	0.765
PI	194	67.5	19.1	13.4	0.866
PN	77	42.9	28.6	28.6	0.714
PS	88	75	10.2	14.8	0.852
PT	44	45.5	25	29.5	0.705
SC	144	87.5	8.3	4.2	0.958
Total	1703				

Table 16. Estimated tortoise abundance in sampled areas of each stratum in 2008. Totals are for long-term strata for which densities were estimated; strata not in totals are indicated by (*). Stratum abbreviations as in Fig. 1

Stratum	Area (km^2)	Proportion sampled	SE(Prop. Sampled)	Sampled area	N (number of tortoises)	95% Confidence Interval for N	
						Lower Limit	Upper Limit
AG	755	0.95	0.024	715	2426	993.6	5924.5
BD	828	0.89	0.032	738	819	311.4	2153.5
BD2*	260	0.77	0.081	200			
CK	3509	0.82	0.030	2890	9222	3117.0	27282.8
CM	4038	0.93	0.023	3755	13705	4941.5	38008.2
CS	1144	0.86	0.031	982	1212	675.7	2174.6
FE	1862	0.96	0.020	1790	8872	4562.0	17255.6
FK	2462	0.96	0.017	2372	848	160.1	4487.2
GB*	1977	0.81	0.027	1604			
IV	2567	0.95	0.021	2442	9335	3775.8	23081.0
JT	1567	0.74	0.033	1159	2031	596.2	6917.5
MM	968	0.86	0.034	836	1583	768.0	3262.2
MM2*	1154	0.82	0.034	949	935	407.9	2142.9
OR	1124	0.73	0.040	821	3100	588.6	16328.8
PI	2334	0.82	0.024	1911	5592	3202.9	9764.3
PN*	1062	0.79	0.039	837	1437	517.3	3993.9
PS*	1117	0.94	0.025	1045	3142	1387.5	7113.4
PT	751	0.96	0.020	722	1790	337.6	9495.6
SC	3447	0.95	0.015	3258	4480	1622.8	12368.5
Total	27356	0.892		24390	65016	44563.9	94853.7

Table 17. Estimated tortoise abundance in sampled areas of each stratum in 2009. Totals are for long-term strata for which densities were estimated; strata not in totals are indicated by (*). Stratum abbreviations as in Fig. 1

Stratum	Area (km^2)	Proportion sampled	SE(Prop. Sampled)	Sampled area	N (number of tortoises)	95% Confidence Interval for N	
						Lower Limit	Upper Limit
AG	755	0.95	0.024	715	5245	2621.2	10494.7
BD	828	0.89	0.032	738	2345	940.1	5848.9
BD2*	260	0.77	0.081	200			
CK*	3509	0.82	0.030	2890			
CM	4038	0.93	0.023	3755	34631	11098.0	108065.1
CS	1117	0.86	0.031	958	1877	936.4	3761.4
FE	1862	0.96	0.020	1790	14420	5845.9	35571.0
FK	2462	0.96	0.017	2372	7738	4065.7	14729.1
GB	1977	0.81	0.027	1604	3513	1377.8	8957.0
IV	2567	0.95	0.021	2442	9859	4255.7	22841.9
JT	1567	0.74	0.033	1159	2628	794.6	8693.0
MM	968	0.86	0.034	836	6131	2992.0	12564.4
MM2*	1154	0.82	0.034	949	2264	903.3	5677.0
OR	1124	0.73	0.040	821	5789	2864.6	11700.3
PI	2334	0.818	0.024	1911	7068	3627.7	13772.2
PT	751	0.69	0.051	522	2628	1049.0	6582.2
SC	3447	0.95	0.015	3258	16060	10131.0	25457.4
Total	25797	0.887		22880	119933	79755.5	180349.9

Debriefing to identify project priorities for future years

Post-season 2008, to implement for 2009

- The new handbook

  The 2008 version was a major revision. It was developed to highlight specialized skills that were the target of instruction. Future versions will be posted as chapters on the Desert Tortoise Recovery Office website, updating chapters as needed.
- Training improvements

  Training in 2008 was more extensive than in the past. Crew comments focused on a need to use more of this time for practice, especially for modifying transects against a variety of obstacles. Participants recommended relatively less classroom instruction and faster feedback on field training performance.
- Imperfect transect completion record should be improved upon

  The new QA/QC procedures include weekly data reviews. Although data are collected about transects that were completed, these data do not allow insight into why other transects were not completed. A separate database was proposed to allow tracking the planning process.
- New USFWS functions

  Performance in 2009 will be affected by the transition to oversight by USFWS of the training and QA/QC teams. In both cases, the group recommended an earlier start to planning for 2009.

Post-season 2009, to implement for 2010

- More consolidated QA/QC I

  If field crews are better able to verify their own data, there is reduced value in ensuring that QA/QC specialists are fellow crew members, and the functions of data collection and processing might benefit from being separated. In 2010, we will use one specialist to interact with 2 field teams.
- Use of weekly assessments to communicate from USFWS to the crews directly

  not only to field team leaders and QA/QC I specialists
- Modification of transects to pull them inside administrative boundaries.

  Modification of the standard transect shape can introduce mistakes; however, as land uses on public lands outside tortoise conservation areas becomes less compatible with recovery of tortoises, we cannot continue to allow transect paths to leave monitoring strata. In 2010, procedures for reflecting away from visible objects like fences and highways will be applied to administrative boundaries.
- Training improvements to target

  In general, training has improved to the point that all crews are fully prepared when they start the field season. With increased expectations on their performance, crews are asking for better understanding of how collected data are used in distance analysis, including the use of telemetry data. They also feel less confident about protocols in rugged terrain than under standard situations, so they want more opportunities for practice and feedback.

DISCUSSION

Sampling representatively in all monitoring strata

In 2007, transects were placed systematically in monitoring strata; the placement scheme itself had a random origin so that transects were located at random with respect to tortoises. The goal of systematic placement is used to provide better coverage of sampled areas, and the set of potential transect locations will be used to sample from in future years as well. Because transects can be rewalked in the future, it is meaningful to collect information describing access and completion of each transect so that this information is available when planning to walk this transect location in future years. In 2008, 4 new strata were surveyed by GBI on a temporary basis; the crew noted that access was much more difficult to plan for than in the long-term strata where they had already been planning entry routes to individual transects in 2007.

Better planning opportunities should improve representative sampling in each monitoring stratum. Another change implemented to improve coverage was redevelopment of the set of rules for changing standard transect protocols when confronted with particular obstacles. These new rules are part of increasing efforts since 2004 to cover all areas within sampling strata. Since 2007, field teams have left transects in their planned locations, reporting any modifications to the transect shape or length. Following the 2008 field season, this reporting was expanded to include describing the reasons for not walking a transect. Because the existing databases only allowed data entry for transects that were walked, an additional database was developed in 2009 to collecting data on the unwalked transects. The current sampling design allowed us for the first time to 1) estimate the actual area to which our density estimates apply; some areas are too rugged for humans to access, and therefore 2) also apply the density estimate to this sampled area to arrive at an abundance estimate in each monitoring stratum.

Density estimates in the Pahrump Valley and north of the Northeastern Mojave RU

The two monitoring strata completed in 2008 in the Pahrump Valley were primarily in the Northeastern Mojave Recovery Unit. The estimated density in these strata, 2.4 tortoises/km^2 (CV=42.5%) compares favorably with estimates in the Northeastern and Eastern Mojave recovery units (1.4 and 3.9 tortoises/km^2, respectively, although the former estimate does not include the Gold Butte stratum).

On the other hand, transects to the north of the Mormon Mesa and Beaver Dam Slope critical habitat units did not indicate high densities north of and adjoining critical habitat. Due to logistical problems in 2008 and then lack of detections in 2009, we have no density estimate for Beaver Dam Slope 2. However, the estimated densities in 2008 and 2009 for Mormon Mesa 2 were consistently lower than those in the long-term stratum of Mormon Mesa.

Training developments

Differences in training results between 2008 and 2009 coincide with a variety of important changes in the training program. In 2008, training was led by UNR and USGS, but this function moved to the USFWS in 2009. There was, however, continuity during this transition since USFWS was working with trainers in 2007 and 2008. Possibly of greater importance, a new data analysis system was put in place in 2009 so that crew summaries could be developed overnight for feedback the next day. Before this, crews might receive delayed input, or might only hear about some performance measures, or might not receive customized guidance on how each crew should try to change their performance. Also in 2009, the training arena had to be moved. The new course is in a less vegetated area, so training results should not be identical in most specifics; however, crews should still demonstrate that they see all tortoise models on the transect line. Only the shape of the detection function should change if the crews are well-trained. Training data in 2009 indicate that crews were detecting all tortoise models on the testing centerline, and first-year crews were performing at least as well as experienced crews. Training in 2009 also included considerable increase in instruction for QA/QC specialists, to which we attribute a dramatic improvement in field season databases.

Improving ability to detect trends in desert tortoise abundance

The primary goal of the monitoring program is to provide population estimates that are relevant to the recovery plan criteria (USFWS, 1994). The priority for these and every other field season is therefore to improve ability to detect trends in desert tortoise abundance at the recovery unit level.

Impact of developing regional G_0 estimates

By completing density analysis outside the DISTANCE software program, we are able to use more than one annual estimate of G_0, This was implemented to achieve a more precise and accurate (less biased) density estimate for each area monitored. We did continue to see regional differences in G_0 estimates, so without localized estimates of G_0 we might introduce bias into our density estimates. On the other hand, Tables 9 and 10 indicate that reducing the number of days monitored in any region has not increased precision as much as hoped.

Year-to-year differences in ability to assess tortoise size

Description of trends year to year will be impacted by any sources of error in annual estimates. Within their 14 m detection width (Fig. 17), Kiva did not report whether 8 of 50 tortoises in 10 strata were larger than 180 mm MCL. This was the first year in which tortoise size class could be listed as “unknown” (based on their location deep in a burrow, for instance), and the number reported of unclassified observations by both teams was unexpectedly high. Consistent with the procedure for all years of this project, unless a tortoise was confirmed larger than 180 mm MCL, it was not included in estimates of density. The effect in 2008 was to base the encounter rate estimate for FK on only one 1 tortoise (while walking 216 km), and to base JT and PT estimates each on 2 detections.

If all unclassified tortoises had been treated as larger than 180 mm MCL and added to the analysis, encounter rates and resulting density estimates for strata in the Western Mojave Recovery Unit especially would be increased considerably over what is reported here (Table 18). The relative importance of this classification uncertainty on the density estimate can be evaluated when compared to CVs for density, which are usually 20-40% at the stratum level when sampling is adequate. Within their 18 m detection width (Fig. 18), GBI did not classify 7 of 164 tortoises based on their size. With so many observations in each of these 5 strata, the impact of excluding relatively few due to uncertainty was small. Due to adequate sampling effort in that part of the desert, the Northeastern Mojave therefore is the only recovery unit in 2008 for which the effect of uncertain size classification could be considered trivial (Table 18).

Table 18. Effect of inability to classify tortoise size on density estimates in 2008. Effects include proportional increases in encounter rate as well as changes in the associated detection curve.

Stratum	Number of tortoises detected on transects…				% increase in density if unclassified tortoises were ≥ 180 mm MCL
	Total	≥ 180 mm MCL	≤ 180 mm MCL	With undetermined MCL	
Northeastern Mojave					
BD	6	4	2		-2%
CS	30	24	5	1	2%
MM	26	20	6		-2%
MM2	8	6	2		-2%
Northeastern Mojave (Pahrump Valley)					
PN	11	8	2	1	10%
PS	30	24	3	3	10%
Eastern Mojave					
FE	10	7	2	1	38%
IV	10	7	2	1	40%
PI	43	34	5	4	7%
Northern Colorado					
CM	5	5			20%
Western Mojave					
FK	4	1	1	2	261%
JT	4	2		2	141%
OR	5	5			20%
PT	3	2	1		20%
SC	8	6		2	69%
Eastern Colorado					
AG	7	7			20%
CK	4	4			20%

Although 4 of the 15 unclassified tortoises were found deep in burrows, 3 others were not classified due to crew uncertainty regarding how closely they could approach tortoises when on the site of a different research project. Subsequent training has focused on troubleshooting this specific situation. The remaining unclassified tortoises were deep enough in burrows that they could not be extracted easily and were not obviously larger than 180 mm. It may be significant that in this drier-than-usual field season, more visible tortoises were found deeper in their burrows than in past years.

For a separate reason, we now collect information to describe the relative visibility of tortoises found in burrows on transects compared to those located at telemetry sites. If this comparison results in treating relatively hidden tortoises at telemetry sites as "not visible" for purposes of estimating G_0, this would compensate as currently intended for tortoises that are hidden and less likely to be seen on transects, but also for tortoises that can be seen but are "invisible" for purposes of analysis because they are so deep in burrows that their size class could not be determined. For instance, consider the possibility of two consecutive years in which 20% of tortoises at a telemetry site were too deep in a burrow to be seen at all. In the second year, another 5% were only visible as part of a limb or scute in the back of a burrow, and another 10% that same year could not be easily extracted from burrows for measurement to confirm their size. Current G_0 estimates for both years would be 80%, but adjustments in later years might use a correction factor based on 80% in the first year but only 65% of tortoises larger than 180 mm detectable in the second year. If any version of this correction factor is later adopted, it could be applied to estimates starting in 2008.

Consequences of insufficient transects

One stratum where only 12 transects were completed (Chuckwalla) also had no detected tortoises in 2009. Consequently, no density estimate was possible for that stratum or for the larger Eastern Colorado Recovery Unit. Whereas much of this program has focused on ways to enhance efforts and develop more precise estimates to detect trends, this example illustrates that attention should also be focused on the lower limits of effort that can produce useful data. There should be sufficient transects in each monitoring stratum each year to detect several live tortoises in each stratum. This is one reason that over the years since 2001, the protocols have changed to allow more kilometers to be walked per day, increasing the number of tortoises encountered. However, the number of transects walked is limited by funding, which was not sufficient to complete more than 10 transects in 7 of the 10 long-term strata in the California portion of the range in 2008 and 3 of them in 2009. Even in areas where tortoises were detected, the basis for density estimates should be more than 10 tortoises per stratum (Buckland et al. 2001), which was only true for 3 of the long-term strata in 2008 and for 8 strata in 2009. These tallies were unaffected by the difficulties classifying tortoises as large enough for analysis (Table 18), but low numbers of transects and observations in the Western Mojave certainly made the impact of uncertainty in size classification more important than in the Northeastern Mojave.

In areas with low tortoise densities, even relatively more transects may not be sufficient for any tortoise detections. This happened in Gold Butte in 2008, where 40 transects were walked, which was nonetheless less than half of what had been planned. Since then, additional funding was available for that stratum and sufficient tortoises were detected in 2009.

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